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AN EXPERIMENTAL STUDY OF
SPATIAL FREQUENCY ADAPTATION EFFECTS
IN THE HUMAN VISUAL SYSTEM

9 Master's THESIS

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# AN EXPERIMENTAL STUDY OF
# SPATIAL FREQUENCY ADAPTATION EFFECTS
# IN THE HUMAN VISUAL SYSTEM

THESIS

Presented to the Faculty of the School of Engineering
of the Air Force Institute of Technology
Air University
in Partial Fulfillment of the
Requirements for the Degree of
Master of Science

by
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Capt USAF
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December 1979

## Preface

The Air Force Institute of Technology (AFIT) and the Aerospace Medical Research Laboratory (AMRL) are both actively involved in research aimed at understanding the operation of the human visual system. One important goal in this research is the development of a model of the visual system that can be used in the analysis of visual tasks and in the definition of design criteria for various visual display systems. This study was conducted in attempt to further our understanding of visual image processing by investigating one aspect of a proposed visual model.

I am indebted to both Dr. Matthew Kabrisky and Maj. Joseph W. Carl for convincing me to undertake this investigation and for the many hours spent in discussing the proposed visual model. A special thanks to Maj. Carl whose proposal prompted this investigation and to Dr. Kabrisky for the uncountable hours spent acting as my advisor, assistant, subject and supporter.

To my wife, April, my loving thanks for her understanding and support in completing this study.

Finally, a grateful thank you to Zona for her dedication in typing and preparing this report.

William A. Clemens

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## Abstract

This report documents an investigation of a hypothesis, based on a receptive field model of the visual system, proposing that the receptive field organization changes in response to a change in the average luminance of the visual stimulus.

Foveal measurements of sinusoidal spatial frequency contrast sensitivity over the range of 2 to 10 cycles per degree were made using a two period forced choice stimulus. Measurements were made at one luminance level while subjects adapted to a 6 cycle per degree sinusoidal grating of the same or different average luminance. The two luminance levels used were 3.50 and 35.0 ft. lamberts.

Testing with adaptation at the same luminance produced a depression in the contrast sensitivity centered over the adapting spatial frequency. Adapting with a different average luminance level failed to produce a shift in this depression. Results obtained for tests without adaptation provide evidence, however, that a change does occur in the visual system as a result of a change in average luminance.

# AN EXPERIMENTAL STUDY
# OF SPATIAL-FREQUENCY-SPECIFIC
# ADAPTATION EFFECTS IN THE
# HUMAN VISUAL SYSTEM

## I. Introduction

### Purpose

The main objective of this thesis is to investigate an experimental hypothesis based on a center-surround receptive field model of the human visual system. This receptive field model leads to the prediction that the known spatial-frequency-specific adaptation depression in the contrast sensitivity curve will shift (to a higher or lower spatial frequency) when the test stimulus average luminance differs from that of the adapting frequency (Ref 3). The specific purpose of this investigation is to determine experimentally if the predicted shift occurs and if so to quantify it in terms of the luminance change.

### Background

The susceptibility of the human visual system to irreversible damage precludes the use of invasive techniques to investigate and quantify its operation and response. As a result, most in vivo investigations of the human visual system are psychophysical in nature. Presenting carefully controlled stimuli to a subject's visual system and observing the subject's response, the investigator attempts to describe the visual system in terms of these stimulus-response relationships.

In conducting a psychophysical experiment, attention must be given to careful control of both the stimulus and the observer's criterion for response if any quantitative statements are to be made concerning the results. Failure to adaquately control either of these parameters can result in inconsistent, incorrect, and inconclusive data.

There are myriad stimuli that might be used in an attempt to determine the characteristics of the two dimensional receptive field of the human visual system. While many different stimuli have been used, none has gained as much attention as the sinusoidal grating pattern. Because of the simplicity of their generation and analysis, they have been used for over 30 years in visual research (Ref 7:107). The set of sinusoidal grating patterns of infinite extent at any frequency and any orientation form an orthogonal set of functions in two spatial dimensions. Hence, any two dimensional spatial pattern can be expressed as a sum of sinusoidal gratings of the proper orientation, amplitude and frequency.

The orthogonal property of sinusoidal gratings allows any complex visual scene to be expressed, via Fourier analysis, in terms of a summation of sinusoidal gratings. Thus any results from investigations of the visual system using sinusoidal gratings can be readily applied to the analysis of more complex stimuli provided only that the visual system can be modeled as a linear system.

Campbell's evidence suggests that the entire visual system can be modeled via linear analysis (Ref 2:552), with the possible exception of low spatial frequencies. Campbell demonstrated that Fourier analysis of complex stimuli and the measured responses to sinusoidal gratings can be used to correctly predict visual system response to a wide range of stimuli (Ref 1:188).

Therefore, sinusoidal gratings form a set of stimuli that can be used effectively to quantitatively describe the response characteristics of the human visual system. They are the stimuli that are used in this investigation.

A sinusoidal grating as shown in figure 1 is typically described in terms of its spatial frequency and contrast. Its frequency is described in terms of the number of cycles subtended per degree of visual field. The contrast of the sinusoidal grating is defined, after Michelson (Ref 10), in terms of the maximum and minimum luminance levels as

$$\text{Contrast} = \frac{L_{max} - L_{min}}{L_{max} + L_{min}} = \frac{L}{2L_{avg}}$$

This is the definition of contrast that is used throughout this research and report. In addition, contrast sensitivity is defined as the reciprocal of the contrast at threshold. The results of measuring visual contrast thresholds for sinusoidal gratings in this research are reported in terms of contrast sensitivities.

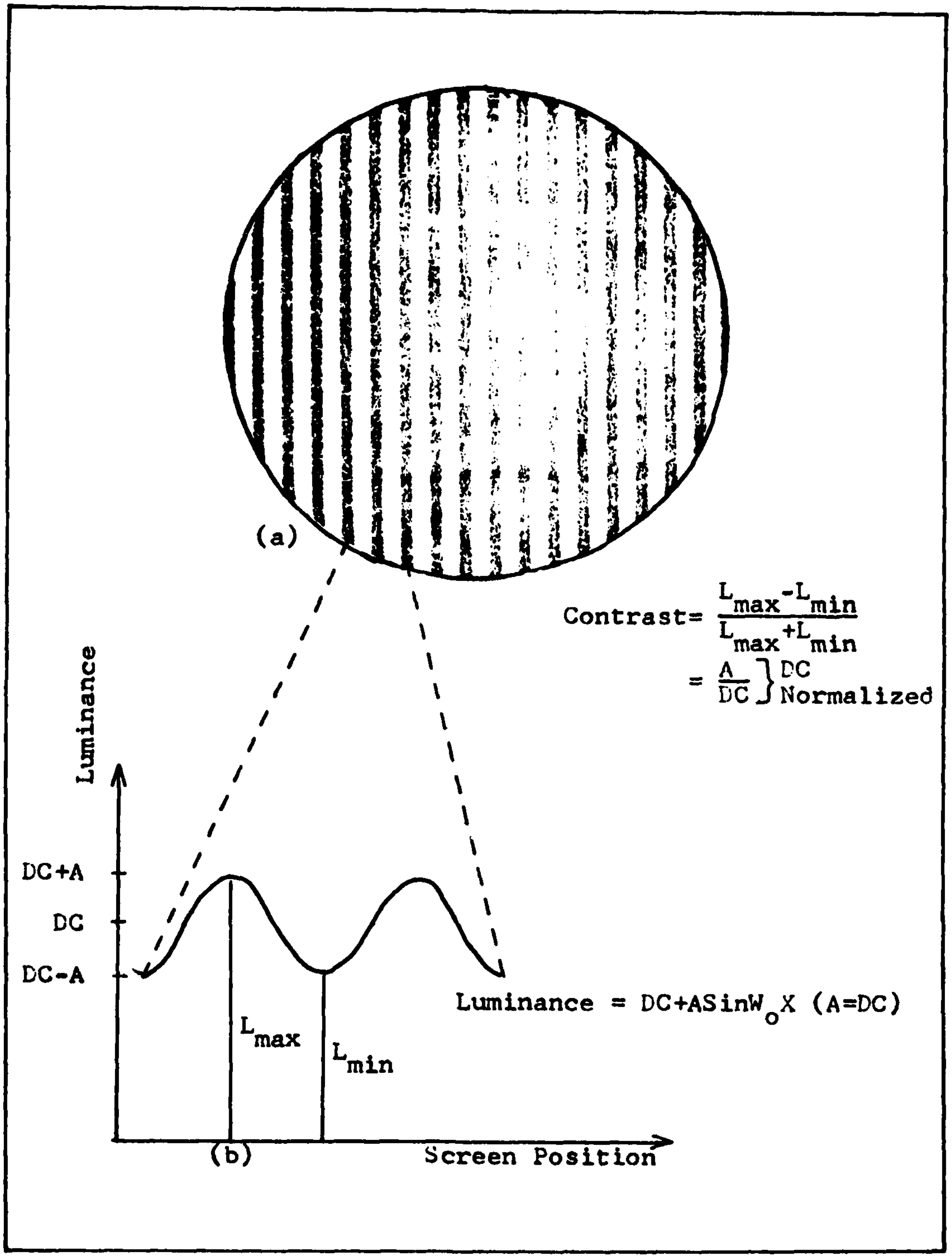


Fig. 1. Luminance Profile of a Sine Wave Grating (a) Sinusoidal Grating, (b) Luminance Grating (Adapted from Ref 16:3)

## II. Experimental Hypothesis

The experimental hypothesis on which this research is based was originally proposed by Carl and studied in a master's thesis by Scheidegg (Ref 16:32). The hypothesis is also described in some detail by Smith in his master's thesis (Ref 17:24-28, which followed the work of Scheidegg. Only a brief description of the hypothesis is included here for the sake of clarity and continuity of this report. The interested reader is referred to Smith and Scheidegg for a more detailed discussion.

Carl has proposed that the frequency specific adaptation depression in the contrast sensitivity response will shift in frequency when a subject is adapted at one luminance level and tested at a different luminance level. This hypothesis is based on a center-surround receptive field model of the visual system in which the receptive field organization is dependent on the average luminance of the visual field (Ref 5:949-951). Based on this model he proposed that the frequency specific adaptation depression would shift to a higher spatial frequency if the visual system is adapted at a low luminance and tested at a higher luminance level.

Figure 2a and b illustrates this hypothesis. Figure 2a shows the frequency specific adaptation depression of a typical modulation transfer function (MTF) curve for a high luminance 6 cycle per degree (CPD) adapting grating and high test luminance. Figure 2b represents the shift in the adaptation

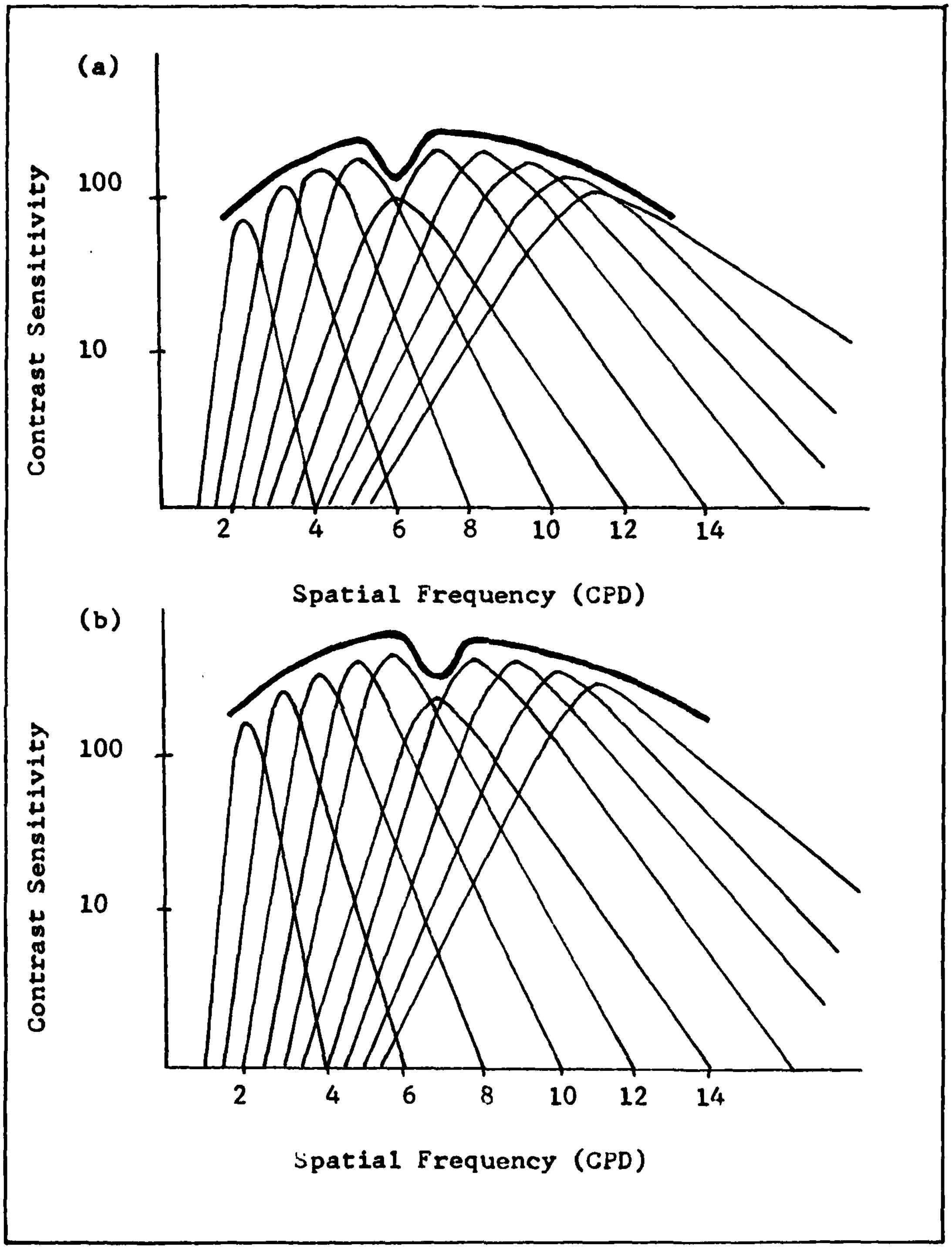


Fig. 2 The Proposed Effect of Luminance Level Changes on the Frequency Specific Adaptation Depression of an MTF Curve Testing at a High Luminance Level and Adapted to a 6 CPD Grating at (a) a High Luminance Level and (b) a Low Luminance Level

depression resulting from adapting at a low luminance and testing at a high luminance. The bold curves in both figures represent the actual MTF curve while the thin curves underneath represent the response of the frequency specific populations of center surround receptive fields.

# III. Apparatus

## Basic Equipment

The equipment used in this research was designed and built during previous thesis efforts at the Air Force Institute of Technology for the specific purpose of measuring the contrast sensitivity of the human visual system. The original design and subsequent modifications of the equipment are described by Nystrom (Ref 12), Hannickel (Ref 6), Quill (Ref 15), Scheidegg (Ref 16), and Smith (Ref 17) in their respective theses. Smith has included a system diagram and table which indicates the original design, modifications and the configuration at the time of his work for each major part of the equipment (Ref 17:101).

A system diagram for this equipment is shown in figure 3. It includes the major equipment components and their interconnections. The direction of signal flow is indicated on each interconnection but the actual signal names and/or number of connections is not included.

As shown this equipment consists of the subject interfaces (a modified 17 inch commercial color television receiver-Sony type 1720, a stimulus request button, and a hand held response box), a pattern generator to produce the signals required to generate the sine wave grating displays, a multiplex controller which interfaces the digital computer to the pattern generator, and the digital computer which controls the display, records responses and computes the results.

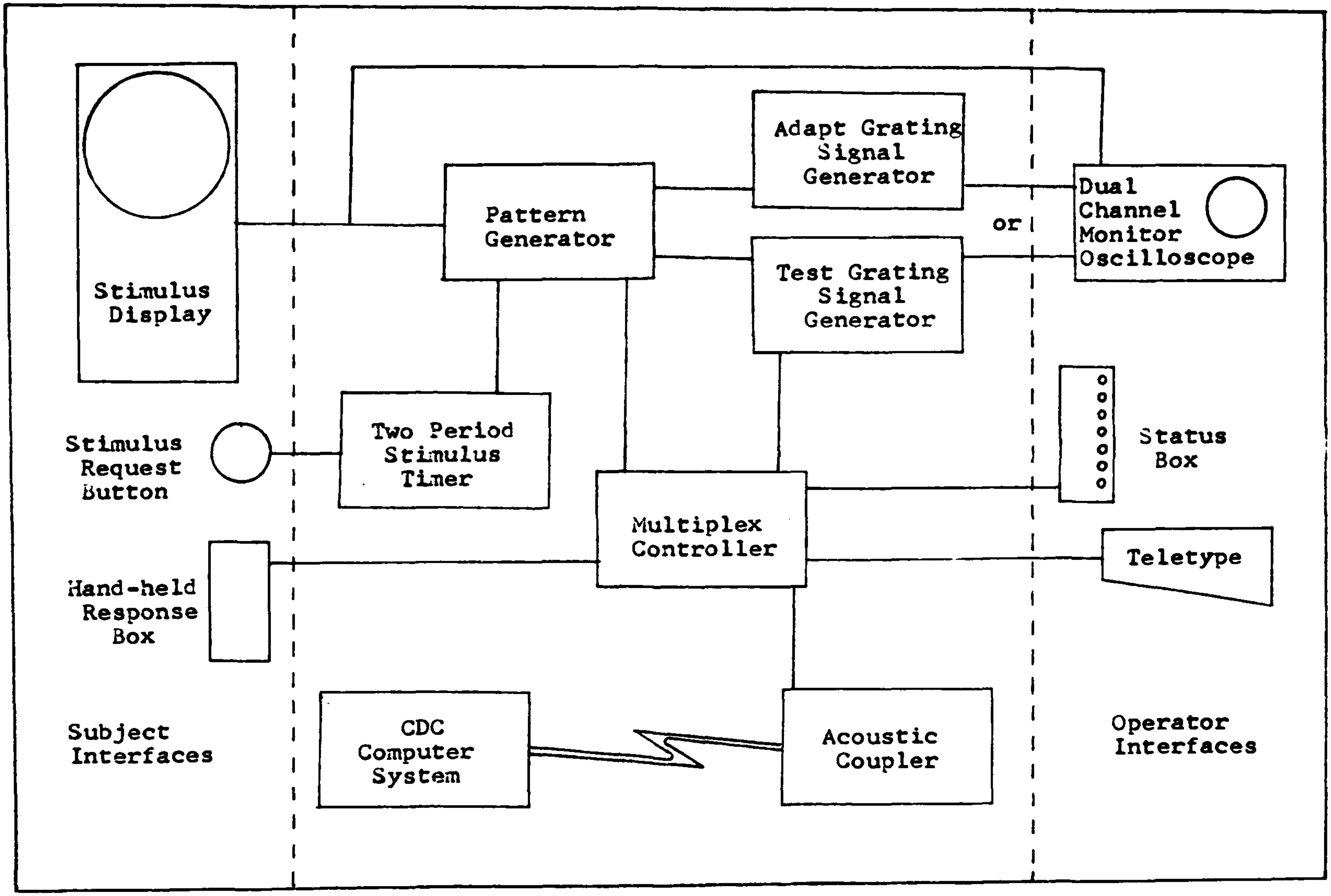


Fig. 3 System Diagram Showing Equipment Interconnections

Required Modifications

Several additional modifications to the equipment were required to accomplish the present research. Specifically, the pattern generator circuit had to be modified to allow presentation of a 2 period forced choice stimulus. The method of providing a horizontal synchronization signal was changed to provide stability and allow continuous variation of the test stimulus frequency. The adapting grating generator was modified to allow the adapting grating to drift continuously across the screen. Finally, the method of changing the brightness level of the display was modified to eliminate long time constant transients in the display brightness. Each of these modifications is described in Appendix A which also includes the current schematic diagrams of the modified circuits.

## IV. Experimental Procedure

### Laboratory Setting

The experiments were conducted in a room with no windows. The only sources of illumination during a test were the TV screen display itself, and a five foot square surrounding the display which was illuminated by an overhead projector. The average luminance of the screen was either 35.0 foot lamberts for a bright stimulus or 3.50 foot lamberts for a dim stimulus. The surround luminance could not be changed during a test and was therefore set at 11.5 foot lamberts, the geometric mean of the two possible screen luminances. The overhead projector was enclosed in an equipment cabinet to prevent distraction of the subject.

The stimulus display itself was a 10 inch diameter circular mask through which the 17" cathode ray tube (CRT) was viewed at a distance of 24 feet. This stimulus subtends 2 degrees of the subject's visual field. To aid the subject in fixing his attention on the stimulus area, a small (¼" diameter) black dot has been affixed to the center of the screen.

The subject sits in a comfortable chair, holds the stimulus request button in one hand, and rests the other hand on the hand-held response box (HRB). A partition separates the operator and stimulus control equipment from the subject. This allows the operator to monitor the progress of the experiment without distracting the subject.

Experimental Paradigm

The basic experiment consists of a two-alternative forced choice test. While viewing an adapting stimulus (either an adapting grating or a blank screen), the subject pushed the stimulus request button to receive the test stimulus. The test stimulus consisted of two short duration periods each marked by an audible tone. These two periods were separated from each other and from the adapting stimulus by blank screen periods at the average luminance of the test stimulus. One of the tone-marked stimulus periods contained the test grating and the other was a blank screen of the same average luminance. The subject then had to respond in which period he saw the test grating. Even if he was not certain he could see grating or was sure he could not see a grating in either period, the subject was forced to choose either "period one" or "period two" as a response by pushing the appropriate button on the HRB.

Before actual testing began the appropriate intervals for the stimuli and between stimulus gaps had to be determined. Based on the discussion by Scheidegg (Ref 16:24) on the choice of a stimulus interval, it was decided to keep the entire test interval at approximately 500 milliseconds.

Initial testing without gaps at the beginning and end of the test period made it extremely difficult to see the test stimulus even at high contrast levels. Also it was noted that if the stimulus timing was a symmetric, the subjects had trouble distinguishing between the two periods even when the inter-stimulus gap was 150 msec. The test stimulus was initially set at 100 msec but was changed to 200 msec when the subjects indicated that it was too short and caused problems in deciding in which stimulus period they actually saw the stimulus.

The timing for the resulting test stimulus interval is shown in figure 4. The top line indicates whether the adapting luminance or test luminance is on the screen. In addition, the sine wave signal indicates the actual time the test grating is present on the screen. The example shown is for the test stimulus in period one. The second line indicates the presence of the tone marking the two test periods.

Each test to determine a subject's contrast sensitivity at a particular spatial frequency consisted of a series of forced choice trials as described above. The presentation of these trials was under computer control. A listing of the computer program used for these experiments can be found in Appendix E. The algorithm used to determine the threshold is described below.

The first trial in each test was at a contrast level well above the subject's threshold. If the subject responded correctly 3 times the contrast was decreased 6 contrast steps, where each step was .05 log units. The subject was again presented three trials. When a wrong answer was given the contrast was raised 2 contrast levels. Now the subject was presented a series of n trials at this contrast level where n is determined by an input to the program (n=10 was used for this research). If the subject responded correctly to more than 90 percent of these trials the main run could begin. If

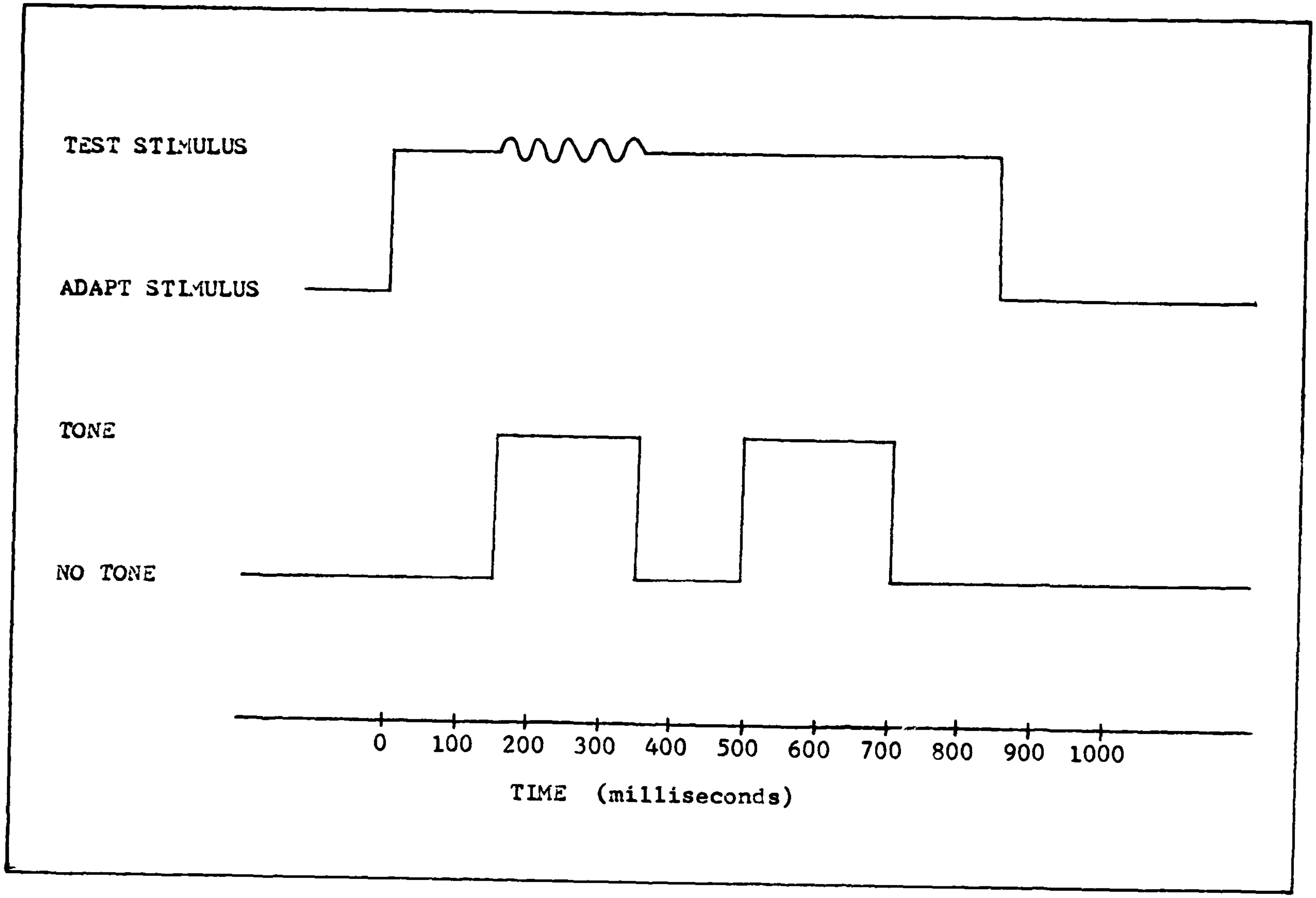


Fig. 4 Two Period Forced Choice Test Stimulus Timing Diagram

not, the contrast level was raised two steps and the trials repeated until a level was reached where the subject responded correctly to more than 90 percent of the trials.

The main run consisted of a series of not more than 7 sets of 10 trials each starting at the contrast level where the subject responded correctly to more than 90 percent of the trials and decreasing one contrast level at the end of each set. The percent of correct response was recorded for each set of trials. This was continued until 7 sets of trials were completed or until the subject had responded correctly to less than 60 percent of the trials in any two sets. The results of these trials were then plotted as percent correct versus contrast sensitivity. An example of this is shown in figure 5. The threshold was determined from this graph as the contrast sensitivity at which a smooth curve drawn through the data points crossed the 75 percent correct point as shown.

## Data Requirements

In order to be able to quantify and compare the adaptation effects it was necessary to first obtain a complete set of data for each subject with no adapting grating present. This set consists of four contrast sensitivity curves as follows:

| | Adapt Luminance | Test Luminance |
|---|---|---|
| 1. | Bright | Bright |
| 2. | Dim | Dim |
| 3. | Bright | Dim |
| 4. | Dim | Bright |

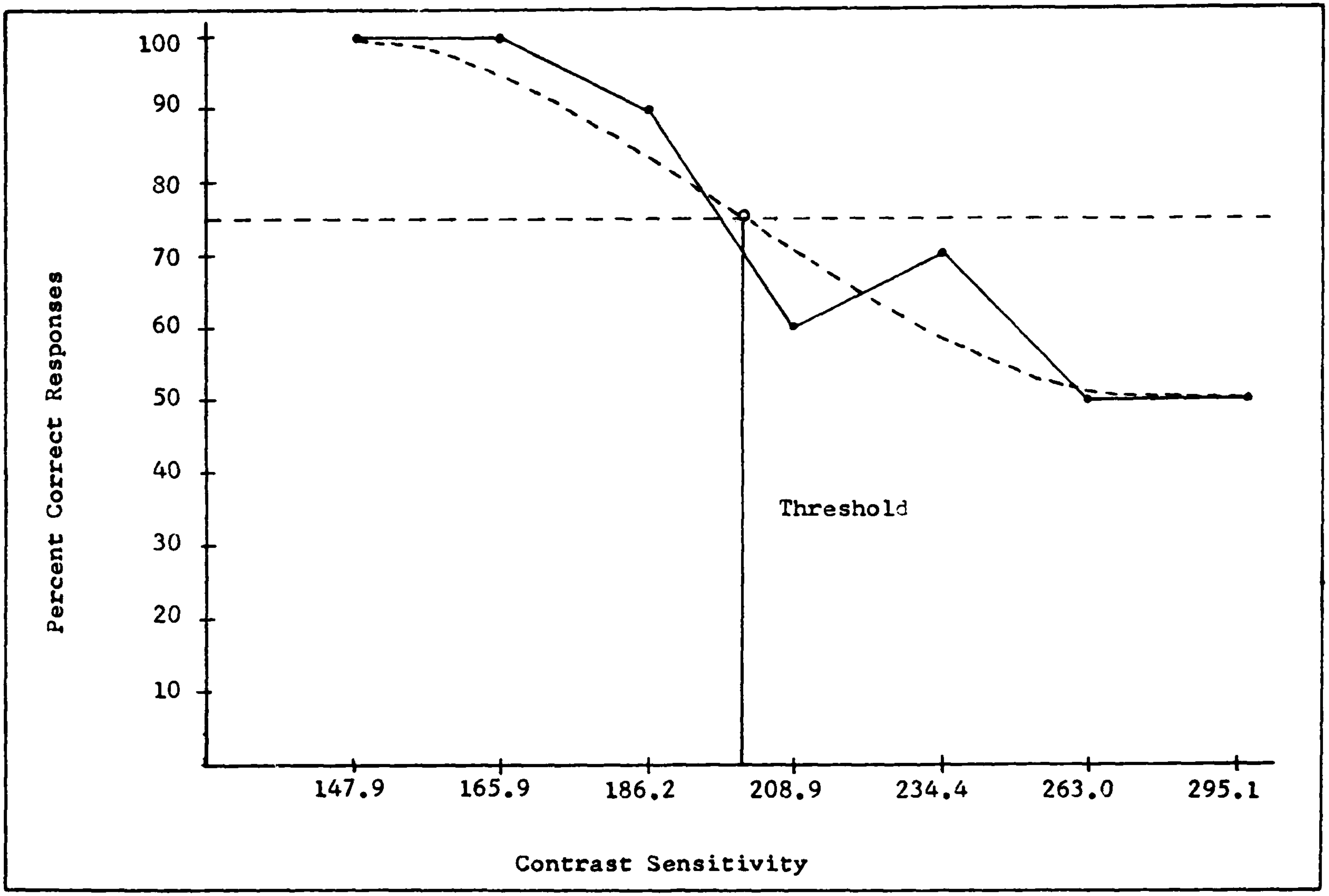


Fig. 5 Plot of Percent Correct Responses vs Contrast Sensitivity to Determine Threshold

Once this set of data has been obtained it can be used as a base line to determine the effects of the adapting grating. It can also be used to normalize the results so that a comparison between subjects can be made.

The desired set of data for adapting gratings would be the same set of 4 curves as above for both a drifting and stationary grating. This was realized to be an unrealistic goal, however, because of the time required to obtain each curve (two to three hours) and in view of the lingering effects of adaptation which Smith reported to be present as much as 48 hours after adapting (Ref 17:34).

## V. Results

The contrast sensitivity curves contained in this section were determined by a version of the two-alternative forced-choice procedure as described in section IV. In all, 5 subjects were tested using this experimental procedure. Only 2 of the subjects were tested extensively, and their data constitutes the major portion of this section.

Many of the curves in this section represent averaged data or data that has been manipulated to aid in comparison; they are annotated as such. All of the original test results are contained in Appendix F. Data manipulations are discussed where they are first used.

The two principal subjects were both familiar with the experimental paradigm and the test structure. One subject (MJK) was much more familiar than the other. Subject familiarity with the equipment and procedures was not considered to affect the test results in any way. The two-alternative forced-choice procedure provides an unbiased estimate of the threshold.

Subject MJK participated in the earlier research of Smith (Ref 17) and Scheidegg (Ref 16), where the "phantom grating" had created a problem. He reported that while this grating was still present, it was no longer confused with the test stimulus. Now the phantom grating appeared in both stimulus presentation periods, and it was known that the test stimulus was present only in one period. The second subject (SDP) also reported seeing the phantom grating, and also indicated that it presented no problem in determining which period contained the test stimulus. The problem of unreliable and inconsistent data resulting from the phantom grating, as reported by Smith (Ref 17), was eliminated with the two-alternative forced-choice procedure.

The four curves in figure 6 represent the baseline data for subject MJK. They represent the results of tests for the four possible combinations of luminance levels (Bright-Bright, Dim-Dim, Bright-Dim, Dim-Bright) for the adapting and test stimuli. Each of the curves is the result of tests with an adapting stimulus of 0 cycles/degree or, in other words, no adapting grating, just a uniform field at the indicated luminance level.

It is interesting to note that the curves follow two different trends below and above a crossover of approximately 6 cycles/degree. Below 6 CPD the curves in which the luminance level changed are depressed with respect to those in which no luminance change occured. Above 6 CPD, however, the adapt dim-test dim curve rolls off crossing the adapt dim-test bright curve which rises to just below the adapt bright-test bright curve.

The known effects of average luminance on contrast sensitivity (Ref 1:554, 13:690) account for the roll off of the adapt dim-test dim curve above 6 CPD. The rise of the adapt dim-test bright curve is not as easily explained. There are no existing experimental data that will explain why the

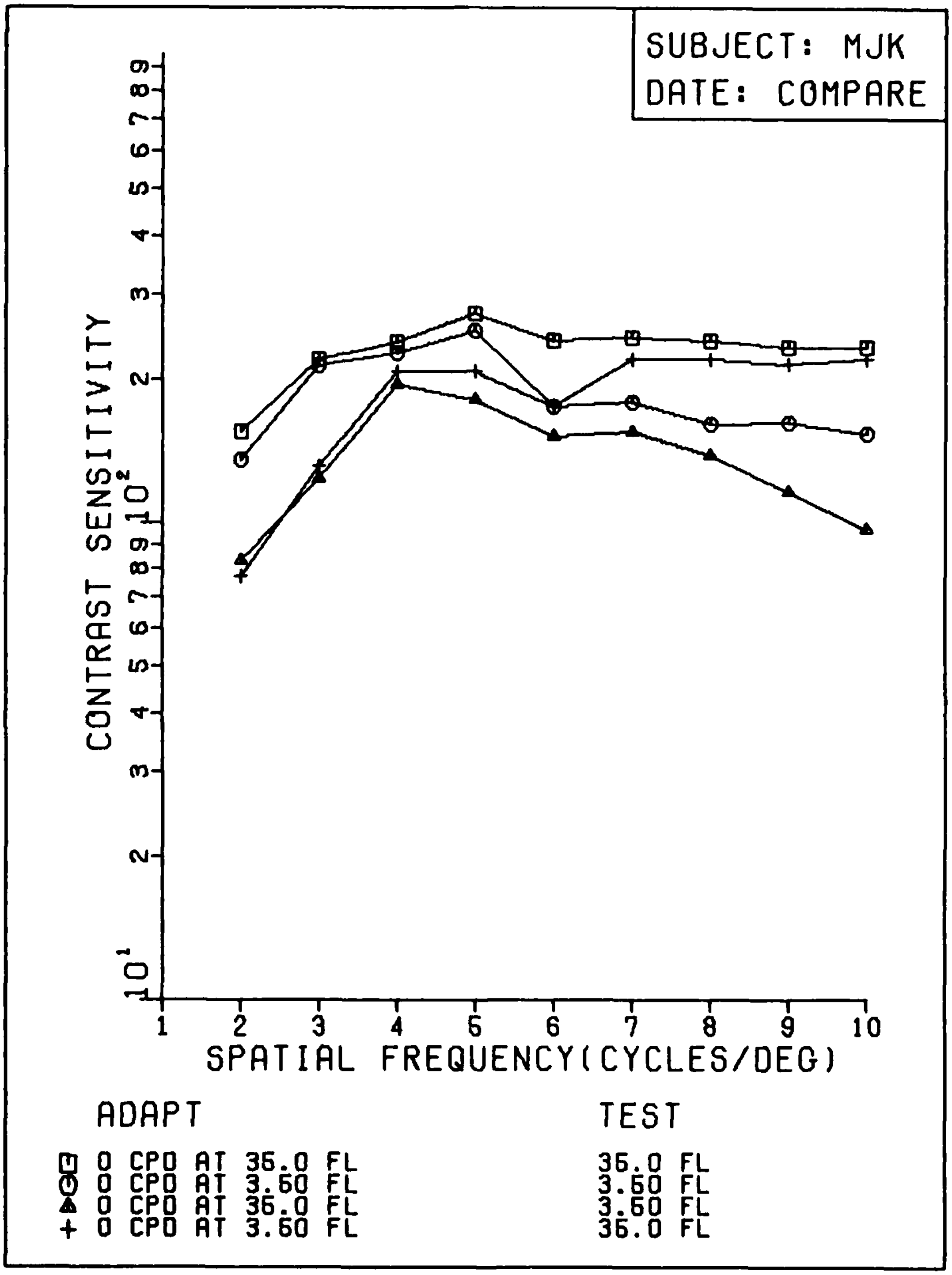


Fig. 6 Baseline Comparison MTF Plot for MJK

depression of the adapt dim-test bright curve evident at low spatial frequencies is almost negligible at high spatial frequencies.

From figure 6 it appears that the effect for bright-dim and dim-bright luminance changes causes about the same depression in contrast sensitivity below 6 CPD. Above 6 CPD, however, while the adapt dim-test bright transition produces almost no depression in contrast sensitivity, the adapt bright-test dim transition results in even greater relative depression than below 6 CPD.

The same test of 4 curves for subject SDP are shown in figure 7. The curves follow the same general trends as discussed above for subject MJK. The major difference is that in general subject SDP's contrast sensitivity is higher than that of MJK. Also, while there is some depression of the contrast sensitivity for subject MJK above 6 CPD as a result of the adapt dim-test bright transition, there is no depression for subject SDP. Finally, the greater contrast sensitivity depression above 6 CPD than below, resulting from the adapt bright-test dim transition for subject MJK is even more apparent for subject SDP.

The curves in figures 6 and 7 form the baseline for comparison of the spatial-frequency-specific adaptation effects for different adapt-test luminance level combinations and between the two subjects. The data shown in these figures are used to normalize the frequency specific adaptation test results in an attempt to remove any differences between curves

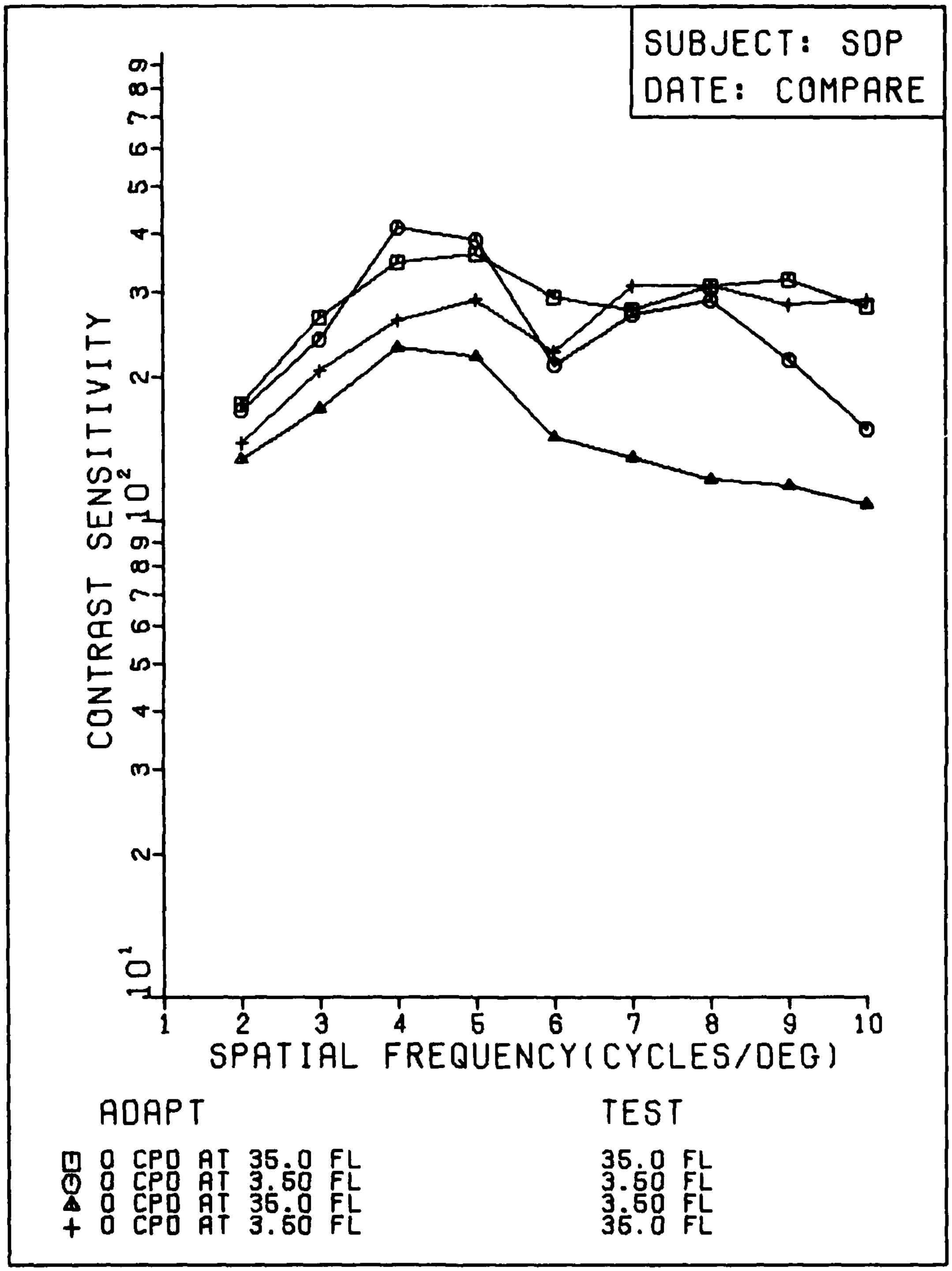


Fig. 7 Baseline Comparison MTF Plot for SDP

that is not directly related to the adapting grating.

The specific method of normalization that was used is as follows.

Relative Contrast Sensitivity Depression =

$$\frac{\text{Contrast Sensitivity (0 adapt)} - \text{Contrast Sensitivity (adapt)}}{\text{Contrast Sensitivity (0 adapt)}}$$

Assuming that the contrast sensitivity measured with an adapting grating present is always less than or equal to the contrast sensitivity without an adapting grating, the relative contrast sensitivity depression will always be a number between 0 and 1.

Figure 8 shows the relative contrast sensitivity depressions for adapt bright-test bright adapt dim-test bright and adapt bright-test dim for subject MJK. The adapting stimulus in each case was a 6 CPD drifting grating at 20% contrast. The general shape and extent in spatial frequency of these curves compare favorably with the results of similar adaptation experiments by Tolhurst (Ref 18) as well as with the results of a spatial frequency masking experiment by Legge (Ref 10).

There is no evidence in either of the adapt-test luminance change curves of figure 8 that indicates a shift in the peak contrast sensitivity away from the 6 CPD adapting frequency. This result might be expected for a drifting adaptation grating if the proposed reorganization were purely retinal. For this reason the tests were repeated using a fixed or stationary adapting grating.

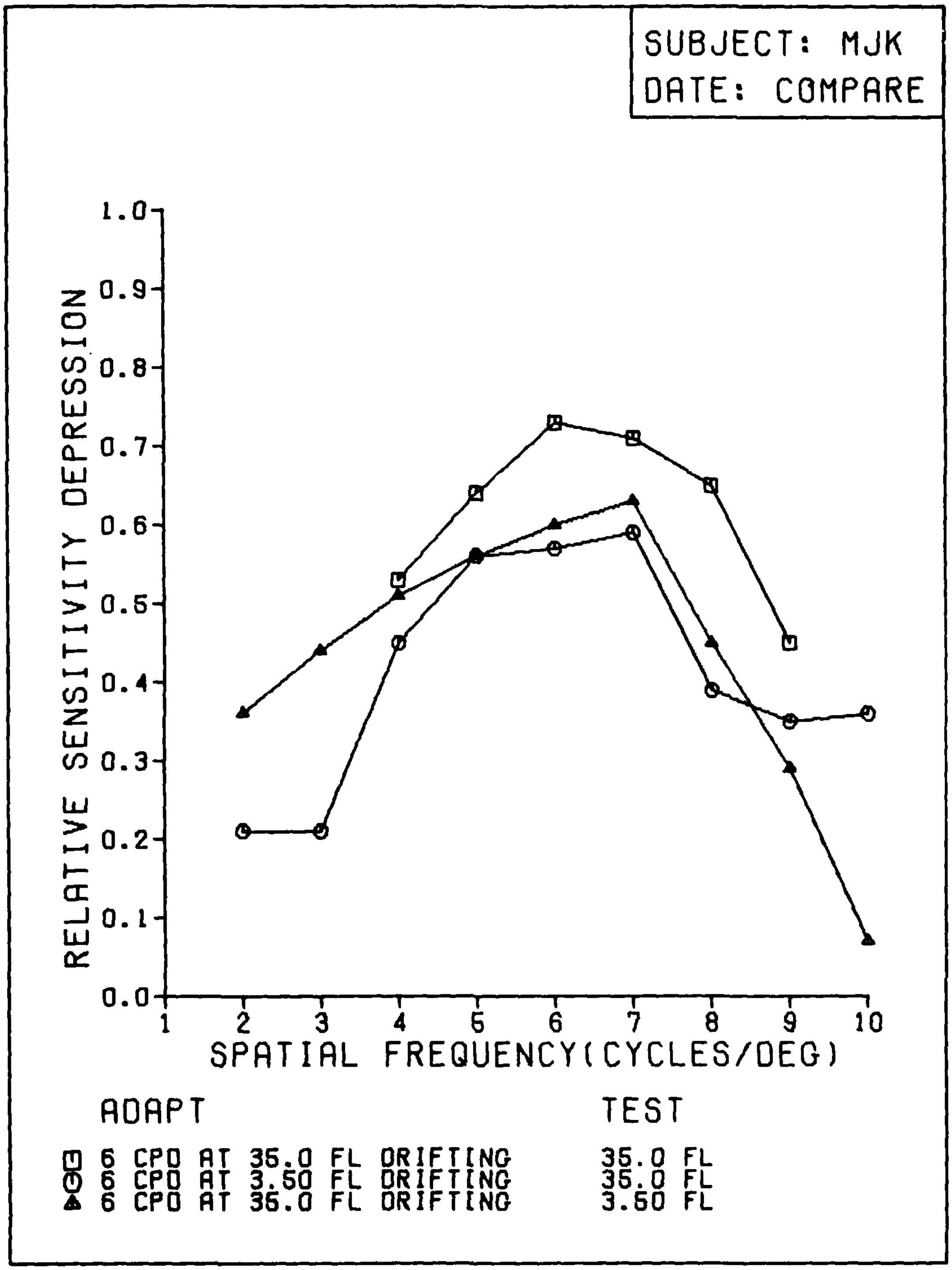


Fig. 8 Relative Contrast Sensitivity Depression for MJK

Figure 9 shows the relative contrast sensitivity depression for a 6 CPD stationary adapting grating, adapting bright and testing dim for subject MJK. The adapt bright-test bright and adapt bright-test dim curves of figure 8 are also shown for comparison. There is no significant change in the relative contrast sensitivity depressions of the drifting and stationary adapting grating.

The adapt-bright test-dim experiment using a 6 CPD drifting adaptation grating was also performed using subject SDP. The results of the test are shown in figure 10 along with corresponding curve for subject MJK. Here again the results indicate that there is no significant indication of any shift in the peak adaptation depression away from the 6 CPD adapting frequency.

Circumstances and time limitations did not allow verification of the other results with subject SDP.

Observations made during the course of the experiments resulted in the investigation of two additional aspects of contrast sensitivity. The first of these was the length of the adaptation depression recovery following an extended period of adaptation. The second deals with a high frequency ripple that was observed in the contrast sensitivity response.

Smith (Ref 17:33-34) indicates that the effects of prolonged adaptation can be observed for up to 48 hours after a test with an adapting stimulus. After observing a similar effect 24 hours after an adaptation test a series of experiments was conducted to determine the long term effects of

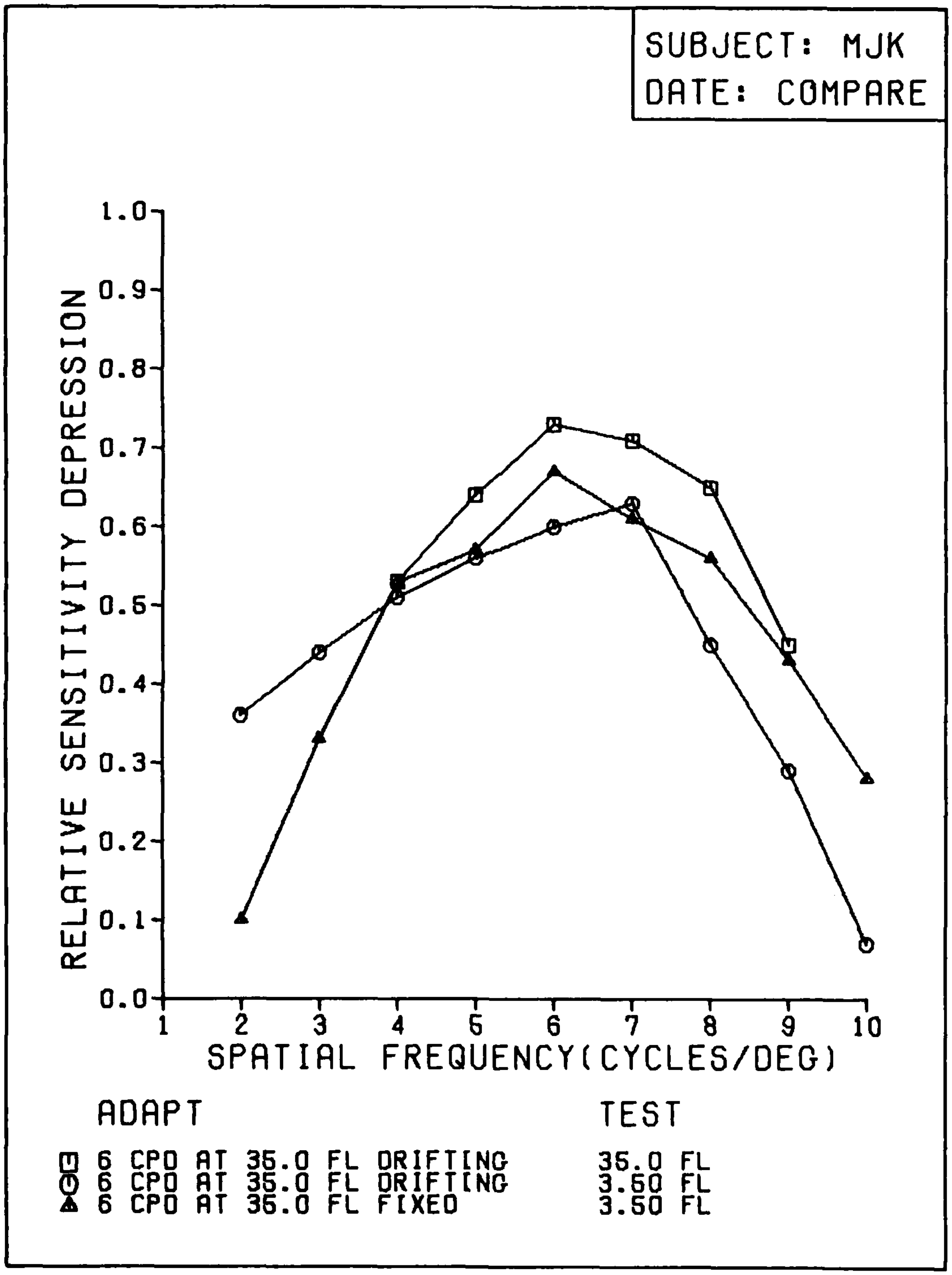


**Fig. 9** Relative Contrast Sensitivity Depression for MJK (Drifting versus Fixed Adaptation Grating)

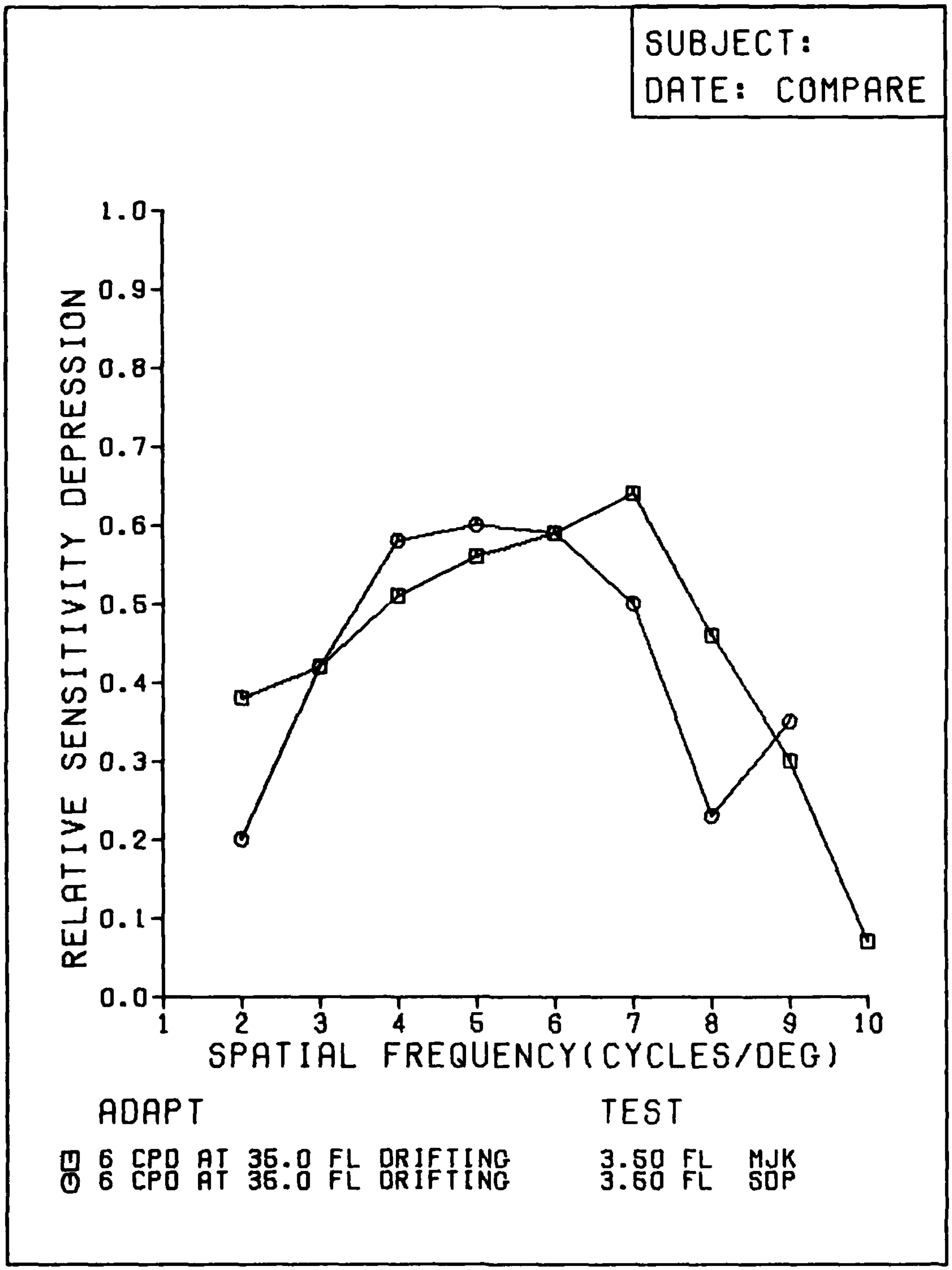


Fig. 10 Relative Contrast Sensitivity Depression (SDP vs MJK)

adaptation.

Figure 11 shows the results for adapting to a 6 CPD grating and then testing at 6 CPD after the adapting grating had been turned off. The three curves are as indicated for 1, 5, and 20 minutes of adaptation before testing. Two observations can be made from these curves. First it is apparent that the longer the adapting period the greater the depression. Second is that the recovery rate is very rapid with all three curves having returned to within 90% of the unadapted value within 40 minutes after adapting.

With the rapid recovery from the effects of adaptation it was apparent that the actual value of the depression had not been determined. In the next experiment the adapting grating was turned on and testing began immediately. Some time later the adapting grating was turned off but consecutive tests continued. In this manner the depression as well as the recovery effects could be noted. Figure 12 shows the results of this experiment. The dark bar directly above the time axis indicates when the adapting grating was present. From this figure it can be seen that with increased periods of adaptation, the recovery period is increased not only as a result of greater depression but also the actual rate of recovery is reduced. In addition with the increased adaptation the initial level-off following adaptation is lower. Following the second adaptation period in figure 12 the sensitivity rises to 175 and then seems to level-off. This is 25% below the original unadapted value of 234. It is apparently this secondary recovery period that Smith observed.

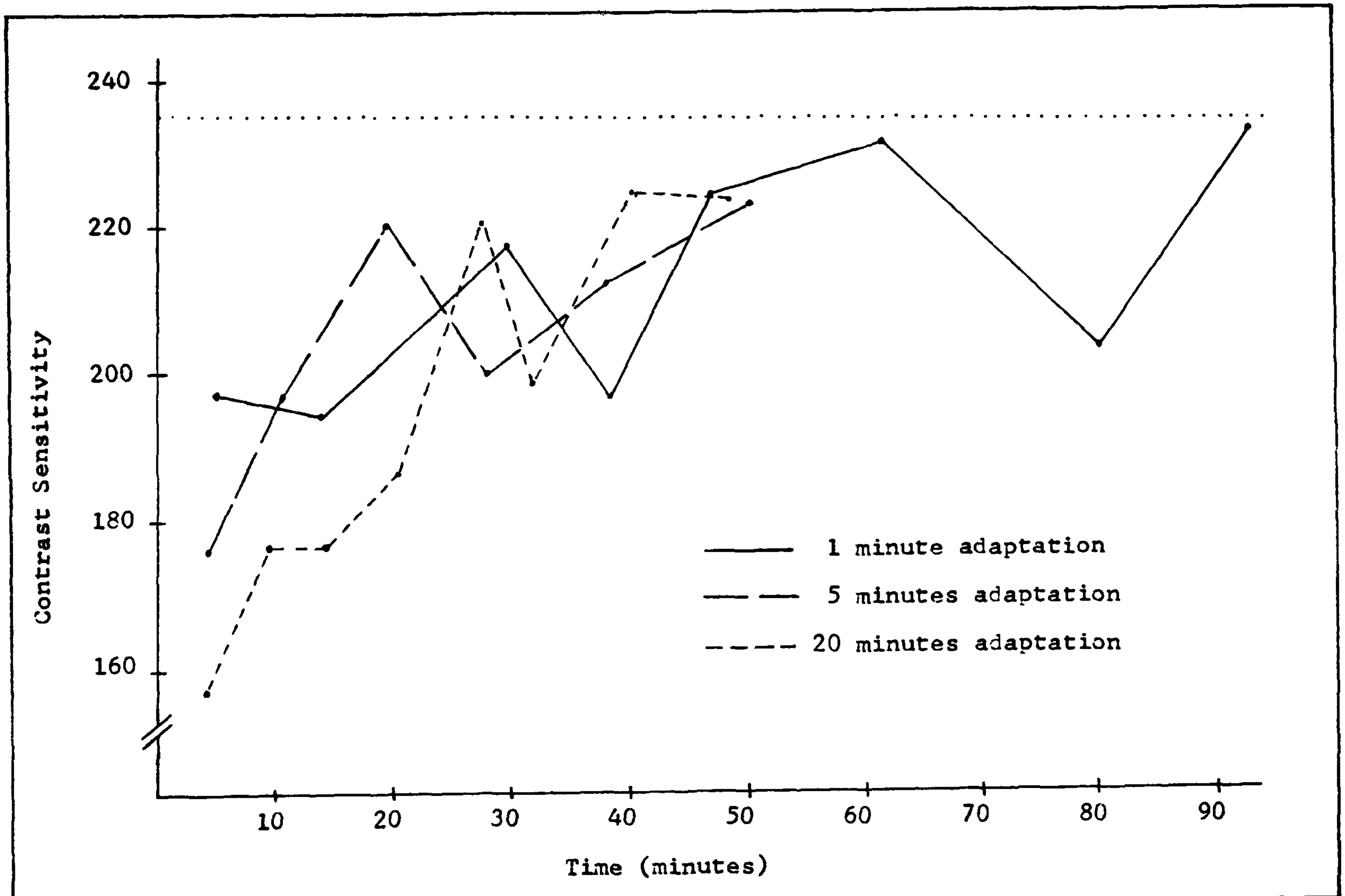


Fig. 11 Contrast Sensitivity Depression at 6 CPD for Various Duration Adaptation at 6 CPD

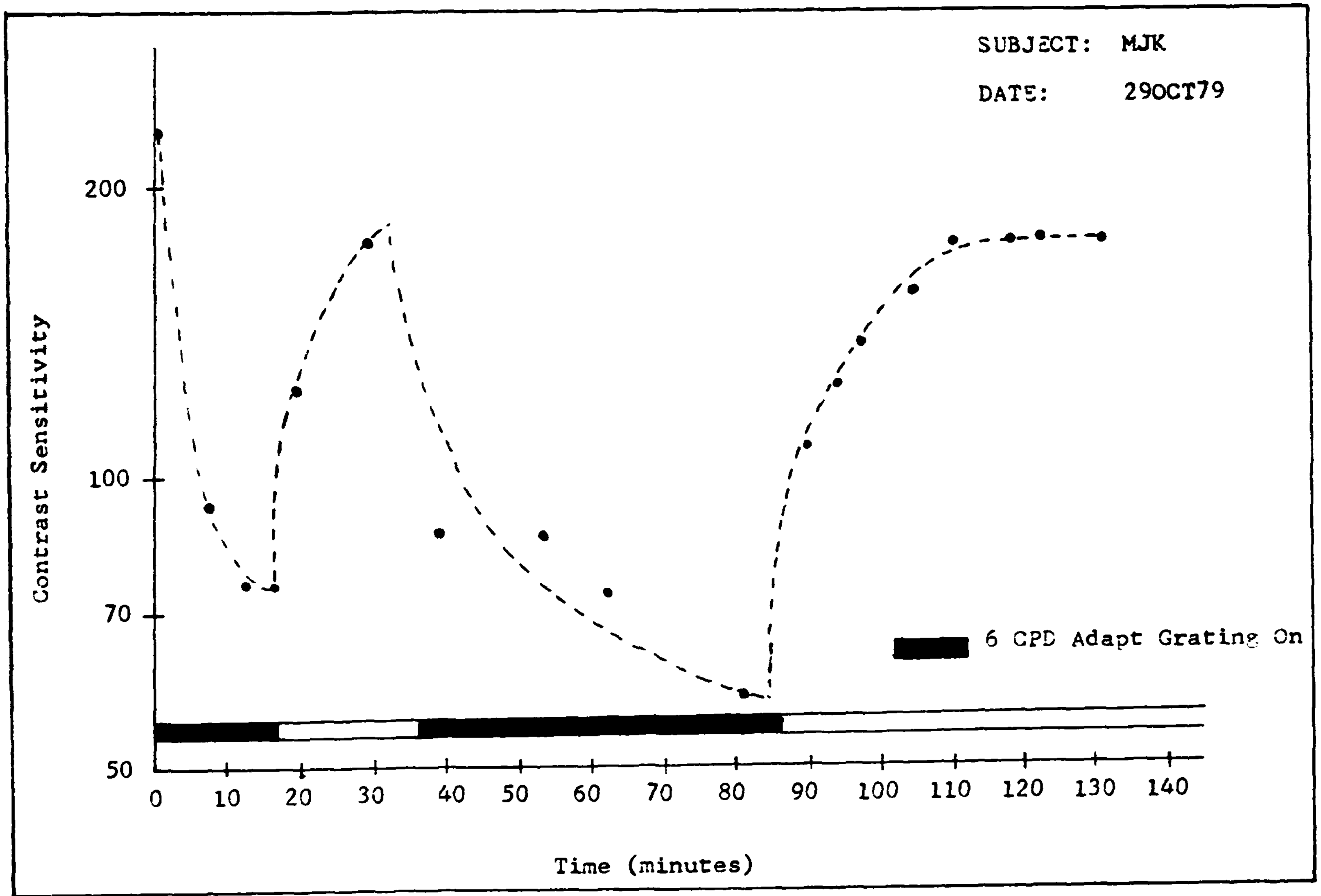


Fig. 12 Contrast Sensitivity Depression and Recovery at 6 CPD for 6 CPD Adapting Grating

The secondary recovery period is shown in figure 13. This is a continuation of the recovery from the last adaptation period in figure 12. A test 4 hours after the adaptation grating had been removed showed the sensitivity still depressed more than 15% below the unadapted value. In a test the following morning the sensitivity had returned to the unadapted value.

Finally figure 14 shows the recovery after adaptation periods of several-hours duration on 9, 11 and 12 October. Tests on the 15th and 16th, three days after adaptation, still show a depression of 25% and a test 7 days after adaptation indicates that the effects have vanished. Unfortunately these data were extracted from other tests and the points shown are the only data available.

The second observation that led to further investigation was a slight dip in the contrast sensitivity curve at 6 CPD. At first this was thought to be a long persistant adaptation effect but was also observed for a subject who had not been exposed to an adapting grating.

The modification to the synchronization circuit in the display generator allowed continuous adjustment of the test frequency and thus a high resolution spatial frequency investigation of this dip. Only minor modifications to the control program were required.

Figure 15 shows the results of a high resolution test for subject MJK. The dips are very apparent and are periodic over the range tested with a period of approximately .7 CPD between successive dips. The test was repeated with subject

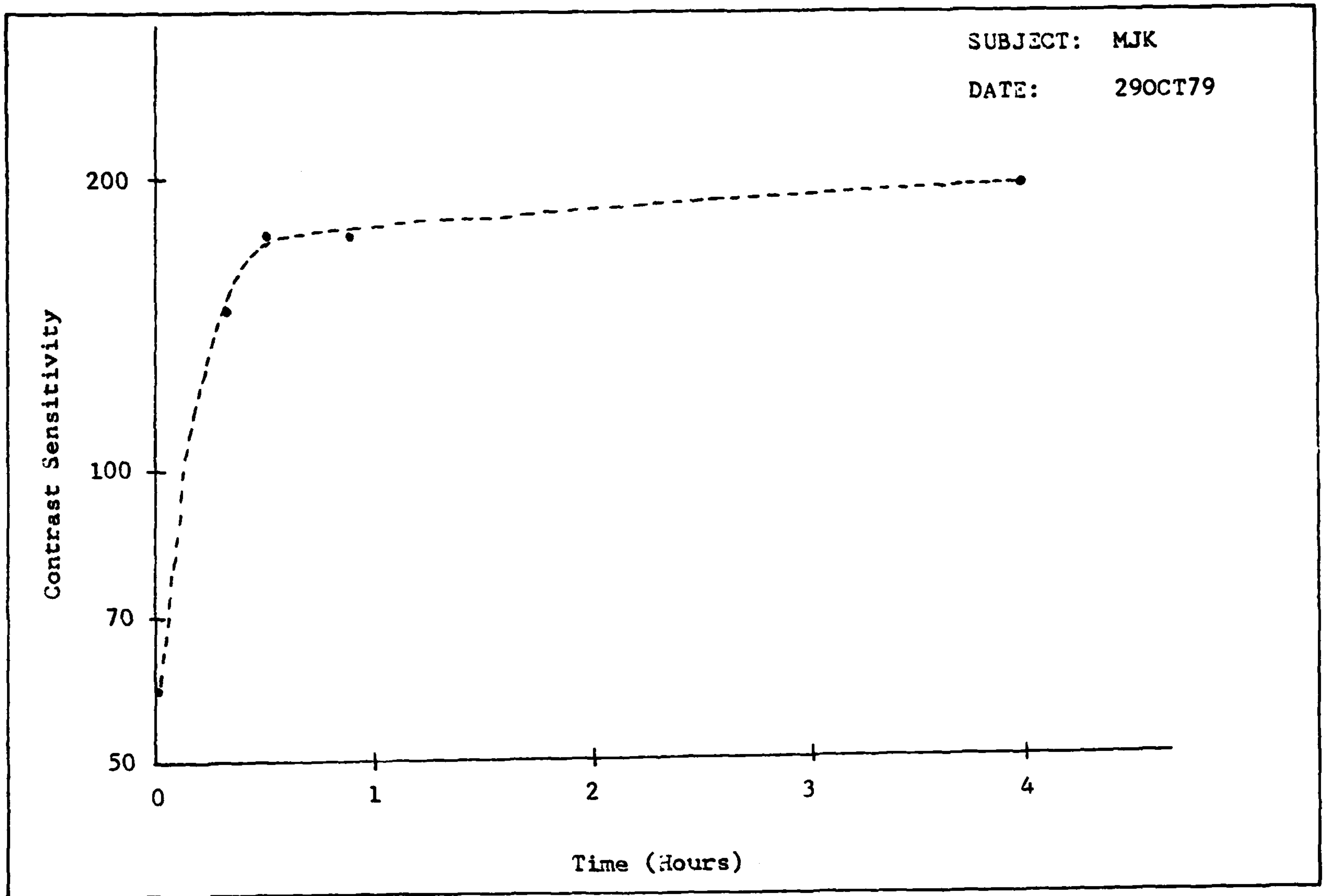


Fig. 13 Contrast Sensitivity Secondary Recovery at 6 CPD for a 6 CPD Adapting Grating

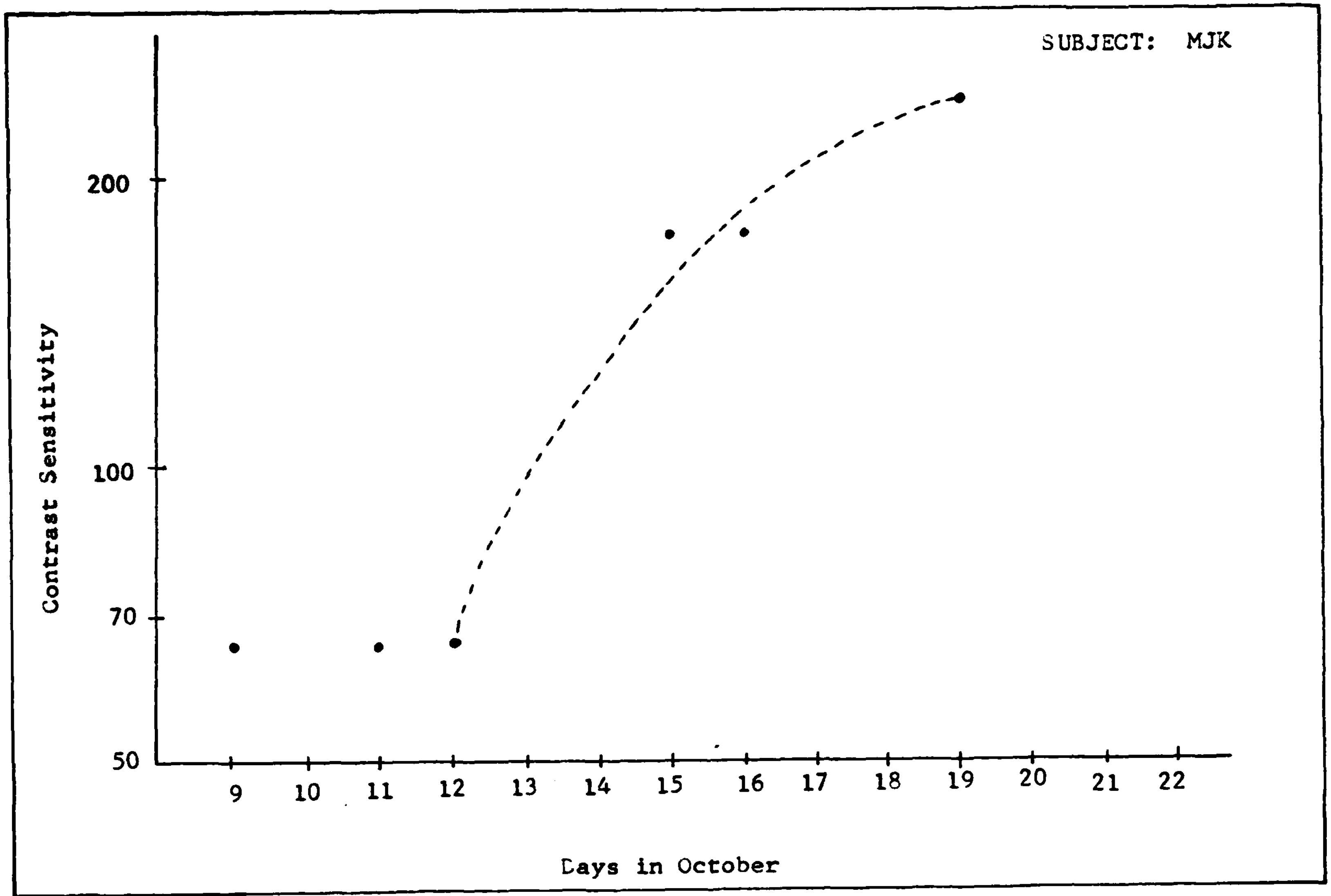


Fig. 14 Contrast Sensitivity Extended Recovery Period at 6CPD after several hours of adaptation at 6CPD on 9, 11 and 12 October

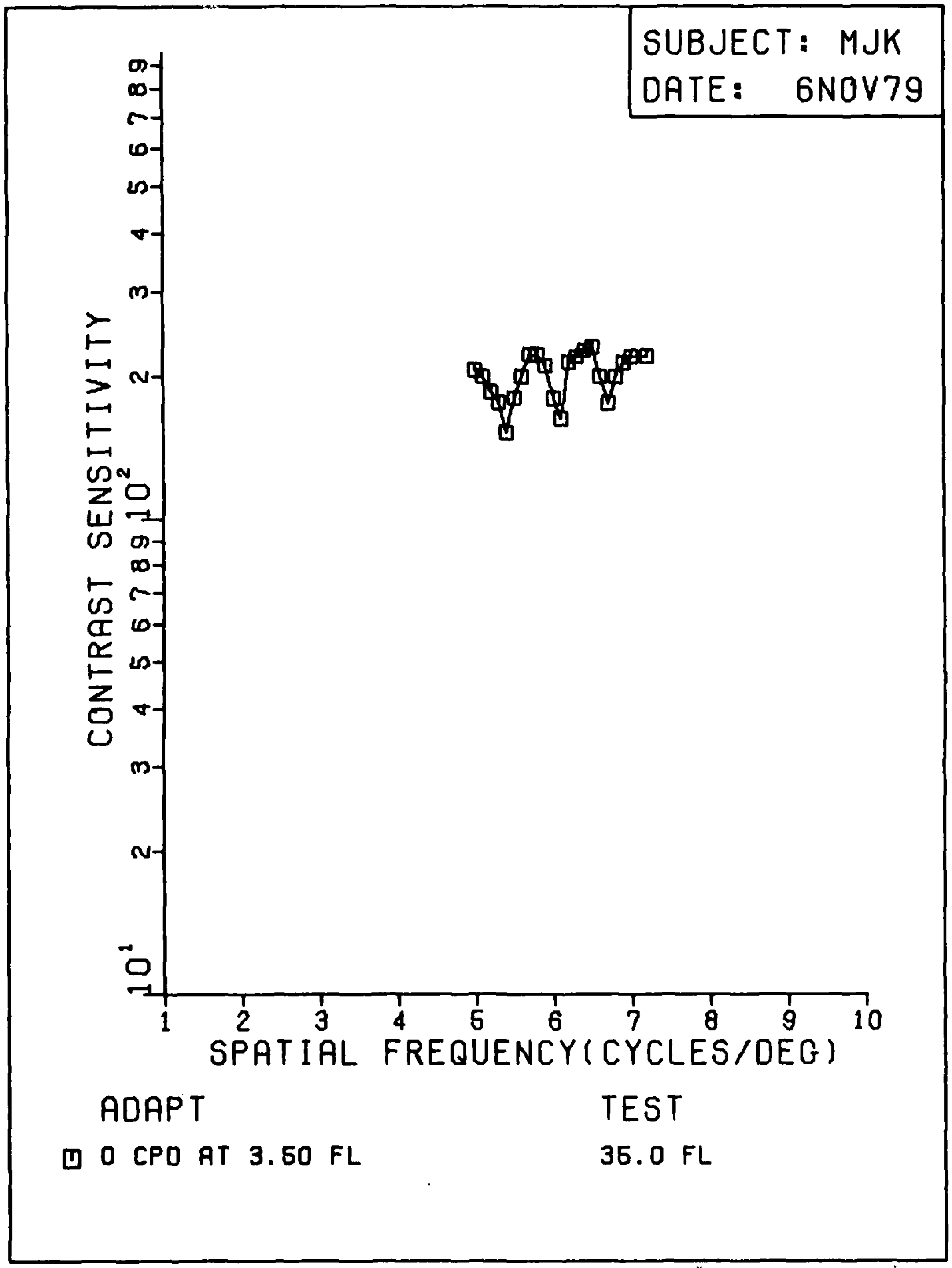


Fig. 15 High Resolution MTF Plot for MJK

SDP who had not recently been exposed to an adapting grating. The tests were done over a wider range of spatial frequencies and with slightly less resolution. The results are shown in figure 16. The dips are also very apparent here and have the same period of approximately .7 CPD. The dips also occur at the same spatial frequencies as for subject MJK.

A third test was conducted, this time for subject WAC whose overall response curve differs greatly from that of either SDP or MJK. The results are shown in figure 17. The ripple effect is also apparent for this subject although the size of the individual dips is greatly reduced and almost disappears at the higher spatial frequencies as the response curve rolls off rapidly.

From the results of WAC it appears that the effect diminishes as the contrast is increased. This is also supported by comparing the results of SDP and MJK. SDP's overall sensitivity is higher than that of MJK and the dips in his response curve are also greater.

Kelly (Ref 8) reported a similar ripple effect in contrast sensitivity measurements as a result of edge effects for small windows. The period of the dips from his calculations, however, were .5 CPD not the .7 CPD that was observed here. All additional attempts to explain the occurance of these ripples in terms of the spatial frequency transform characteristics of the display window failed to produce any useful theoretical model.

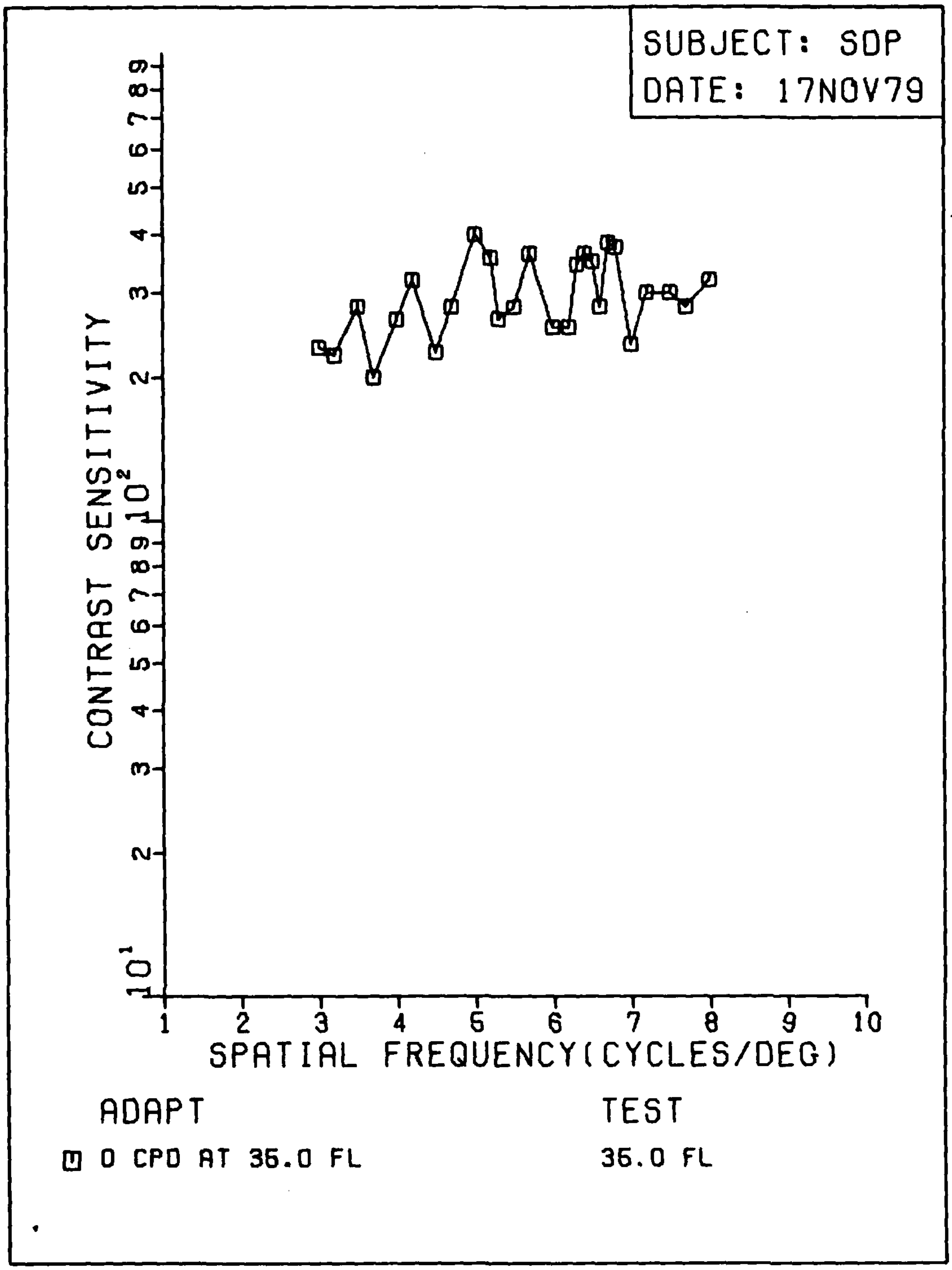


Fig. 16 High Resolution MTF Plot for SDP

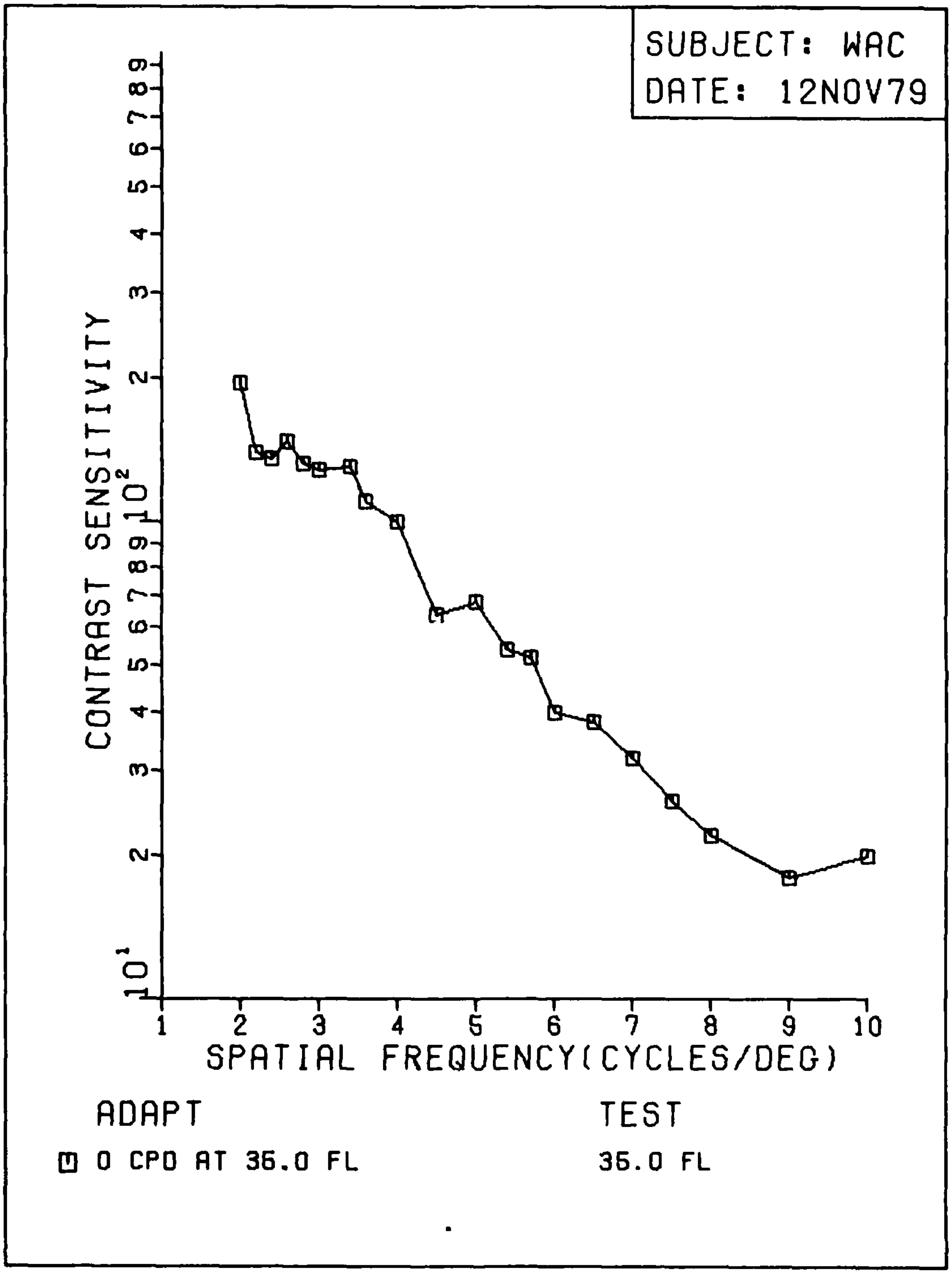


Fig. 17 High Resolution MTF Plot for WAC

## VI. Conclusion

The results indicate that there is no apparent shift in the frequency specific adaptation depression resulting from a change in the average luminance of the visual stimulus. While this contradicts the results presented by Smith (Ref 17), evidence of ripples in the contrast sensitivity response have been presented that could account for his findings. The results, in any case, neither confirm nor deny the existance of center-surround receptive fields whose organization changes in response to luminance changes in the visual field. The results only indicate that any change that occurs is not evidenced by a shift in the frequency specific adaptation depression as was originally predicted, unless the shift is small compared to the one cycle per degree resolution of this experiment.

The results obtained for tests without adaptation are evidence that, in fact, some change does occur in the visual system as a result of a change in average luminance. The fact that this change is not evidenced in the manner predicted by the model is only an indication that the model is not completely correct. That the model is correct in other instances indicates that any simple model is perhaps inadequate to describe the complex organization of the visual system.

## VII. Recommendations

The single most important recommendation that can be made is the need for investigation of the high frequency ripple observed in the contrast sensitivity curve. Until the origin of this ripple is determined and it is eliminated or at least quantified there will be some question in any data obtained using this equipment. This is a most important consideration and should be accomplished before any further tests are conducted.

A second recommendation is that the circuit that provides the timing for the 2 interval forced choice stimulus should be hard wired to insure reliable operation during future experiments. This circuit currently is constructed on an Elite 1 design board.

Finally, additional experiments should be conducted to confirm the results of this research. In particular the tests should be repeated using an adapting grating frequency other than 6 CPD. The reason for this is that 6 CPD is the approximate frequency for the crossover of the luminance changes effects noted in the unadapted baseline curves for both subjects tested. Since the effects for luminance changes are different above and below 6 CPD data using an adapting grating in both these areas should be obtained.

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Appendix A

## Equipment Configuration

This appendix contains the current schematic diagrams for the equipment that was modified during this research. As discussed in section III, four modifications of the equipment were required. Each of these modifications is described in this appendix.

The addition of a two period forced choice stimulus was the most significant change made to the equipment. The original equipment allowed only a single test stimulus period in each trial. The two alternative forced choice test requires two test stimulus periods in each trial. Both of these periods must be marked so that they can be easily identified by the subject. This marking was accomplished by use of an audible tone which was turned on only during the two stimulus periods. A schematic of the resulting two period stimulus timer is shown in figure 18.

The stimulus timer shown in figure 18 was interfaced with the pattern generator replacing the single interval timer in the pattern generator. A timing diagram for this two period timer is shown in figure 19. The time intervals shown are those used in this research. The external timing resistors on each of the one-shot timers can be adjusted to produce a different timing sequence if required.

A means of having the adapting grating drift slowly across the screen was desired. This required the generation of a sine wave signal at the adapting frequency that drifted continuously with respect to a reference sine wave. Two sine waves 90 degrees out of phase and at the adapting frequency were modulated by two low frequency sine waves of the same frequency (2 Hertz) and also 90 degrees out of phase. This was accomplished using the voltage controlled amplitude (VCA) feature of two Wavetek Model 186 5 MHz phase lock sweep generators. The resulting signals were summed using an operational amplifier. The output of this amplifier is a sine wave at the adapting frequency that drifts continuously with respect to the original signals.

Figure 20 is a diagram of the equipment connections required to produce this drifting adapting grating. As shown, the output of the operational amplifier is not used directly for the adapting grating signal but is used to phase lock another Wavetek generator. This was done to eliminate the slight amplitude variation present in the output signal and to allow adjustment of the adapting grating amplitude independent of the drifting circuitry.

The final two modifications to the equipment resulted from the need to eliminate transients in the display brightness which occured when switching between the adapting and test stimulus. The first involves the method of generating and providing horizontal synchronization to the television receiver and the second is directly related to the method of changing brightness between a bright and a dim stimulus.

A brightness level change was noted when switching from the adapting to test stimulus when both were at the same luminance level. The source of this change was traced to the length of the interval between horizontal synchronization pulses. The exact length of this interval was dependant on the frequency of the grating signal and varies by several microseconds when the test signal generator frequency was varied. A one microsecond change in the length of this interval produced a brightness change of several foot lamberts in the bright luminance display. Adjustment of the test frequency generator in an attempt to eliminate this brightness change was unsuccessful; resulting in either an unstable display or the wrong spatial frequency.

This problem was corrected by separating the horizontal synchronization signal from the video input. The horizontal synchronization signal is derived only from the adapting signal generator. The horizontal synchronization pulses are then used as input to the gate of the Wavetek Model 186 signal generator used for the test grating. This insures that the test grating will be synchronized. Only the video signal itself is switched when changing from the adapting to the test stimulus eliminating the possibility of any brightness change from a change in the horizontal synchronization signal, since the horizontal synchronization signal does not change. The use of the gate feature of the Wavetek generator also allows continuous adjustment of the test grating frequency while maintaining synchronization.

Finally, a slow time constant transient was observed when the intentional brightness change was made when switching between the adapting stimulus at one luminance level and the test stimulus at another luminance level. This transient lasted several hundred milliseconds and produced a significant difference between the luminance levels of the first and second periods of the two period test stimulus.

The transient in the brightness level was eliminated by modifying the method of changing the luminance level. Originally the luminance level was changed by switching the resistance in the brightness control circuit. Now the DC level of the video input is used to change the brightness. This is accomplished by changing the DC offset voltage at the input to the last operational amplifier (A6) in the video chain of the pattern generator as shown in figure 21, the schematic diagram of the pattern generator.

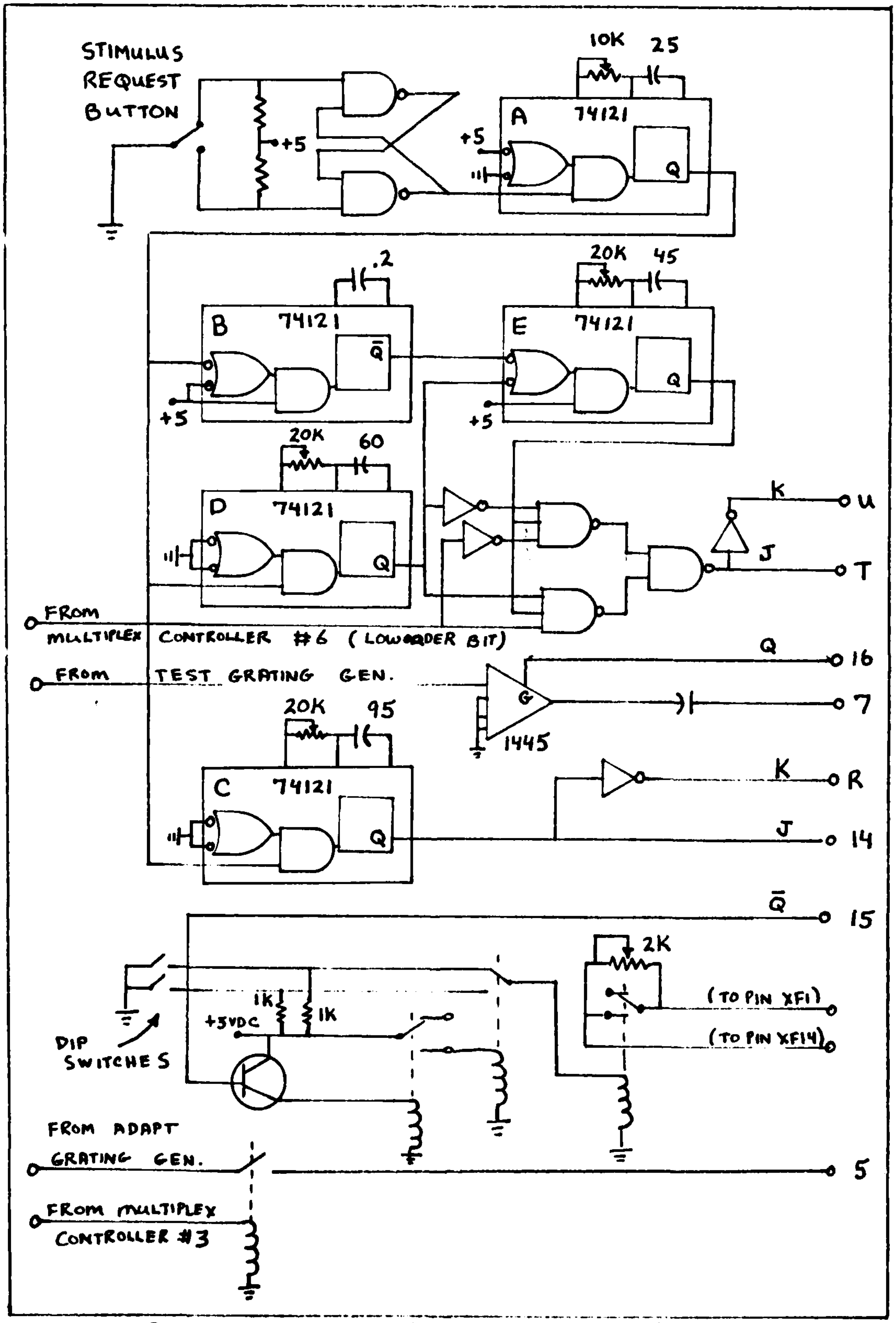


Fig. 18 Two Period Stimulus Timer Schematic Diagram

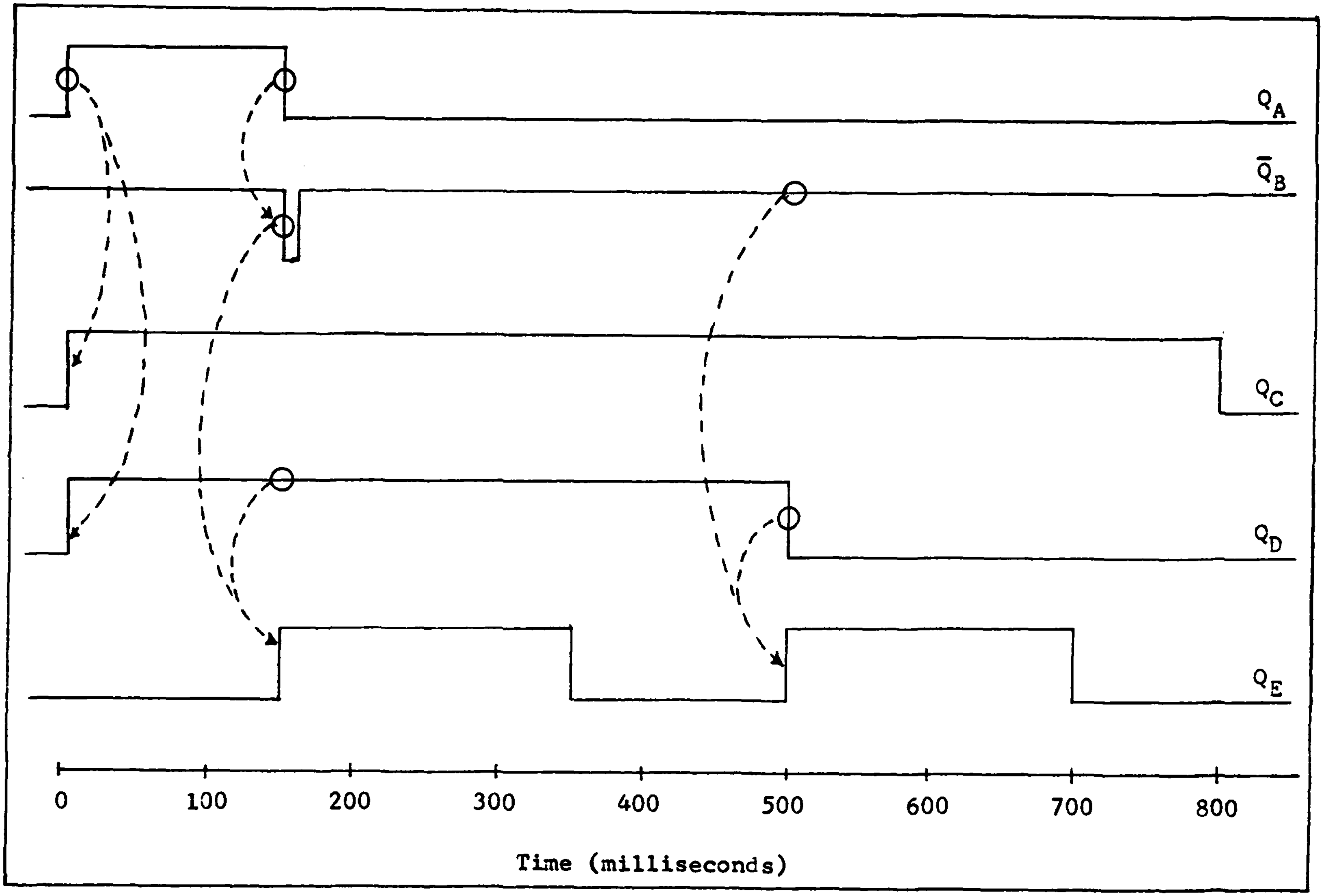


Fig. 19 Two Period Stimulus Timer Timing Diagram

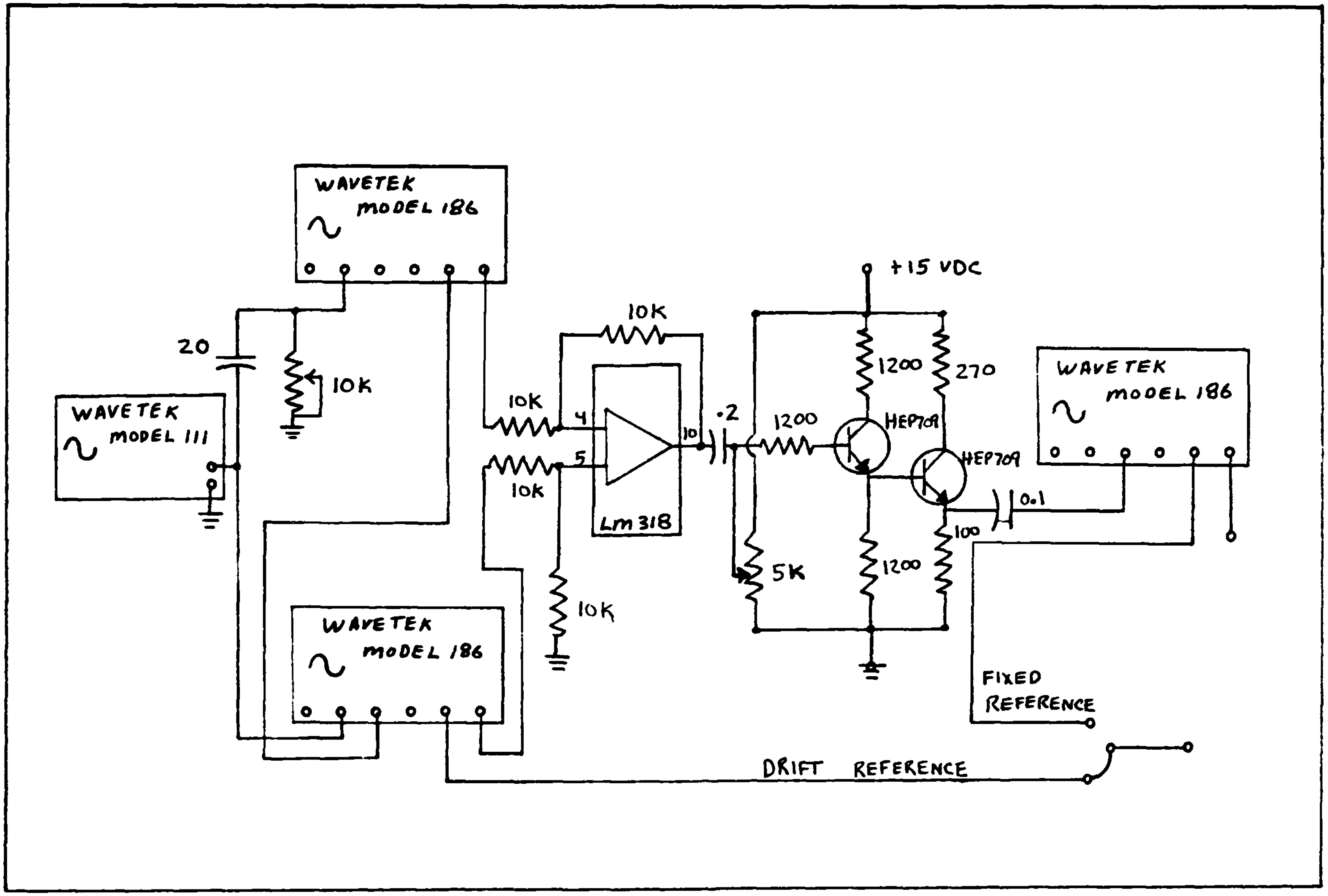


Fig. 20 Adapting Grating Generator Schematic Diagram

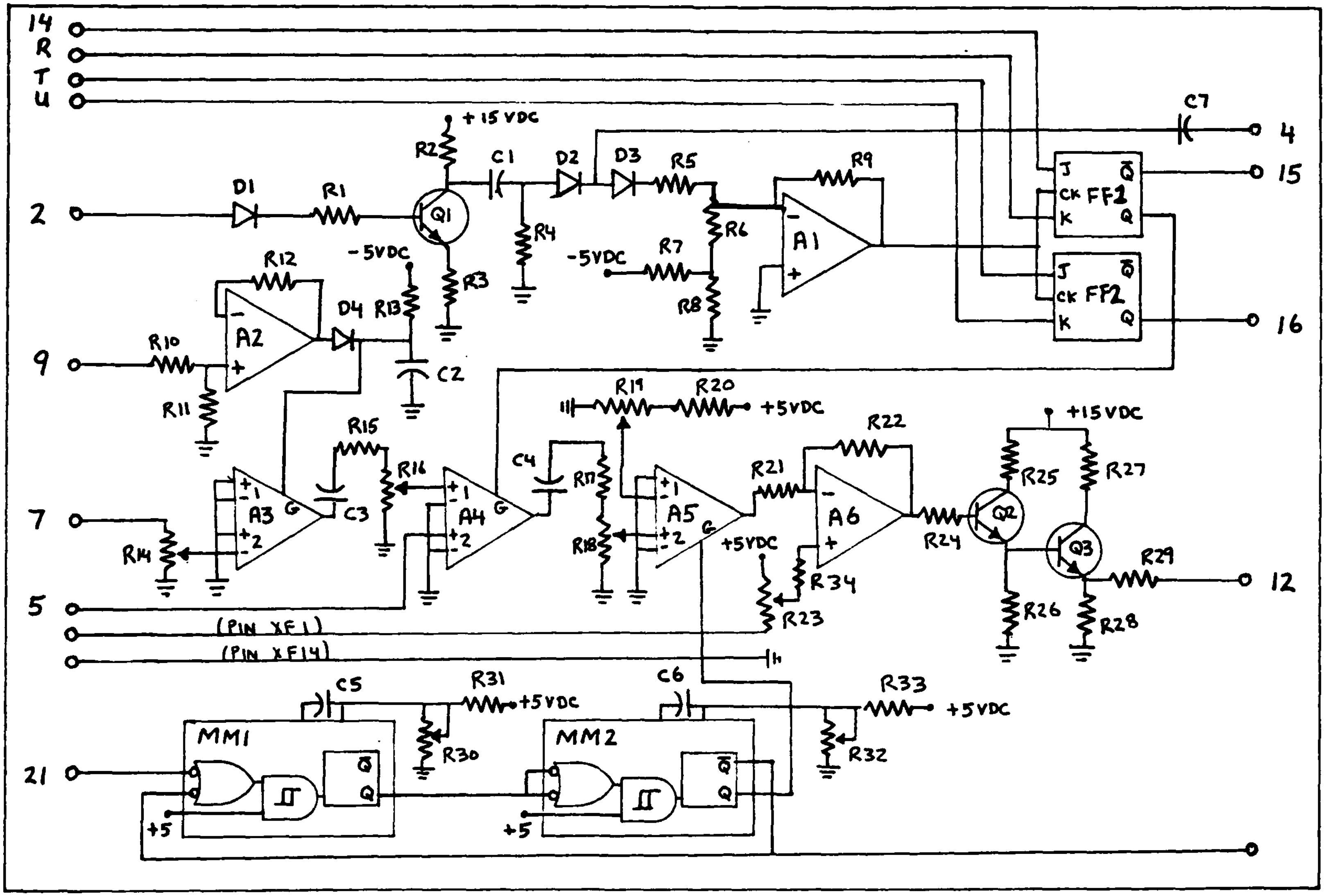


Fig. 21 Modified Pattern Generator Schematic Diagram

## TABLE I

### Pattern Generator Component List

| Component Number | Value |
|---|---|
| R1, R24, R26 | 1200 |
| R2, R8 | 8200 |
| R3, R29 | 180 |
| R4 | 3300 |
| R5, R6 | 15000 |
| R9*, R21, R22, R30*, R32*, R33 | 10000 |
| R11, R12, R13, R15, R17, R20 | 2200 |
| R14, R16, R18, R19, R23 | 500 |
| R25 | 100 |
| R27 | 68 |
| R28 | 470 |
| R31 | 12000 |
| R34 | 6800 |
| C1, C6 | .01 |
| C2, C3, C4, C7 | .1 |
| C5 | .003 |

| Component Number | Description |
|---|---|
| D1, D2, D3, D4 | 1N914** |
| Q1 | HEP50 |
| Q2, Q3 | HEP709 |
| A1, A2 | ½SN72558 |
| A3, A4, A5 | MC1445 |
| A6 | LM318 |
| MM1, MM2 | SN74121 |

Note: Resistances are in ohms. Capacitances in mfd.

* Variable resistors

** Any silicon diode is suitable

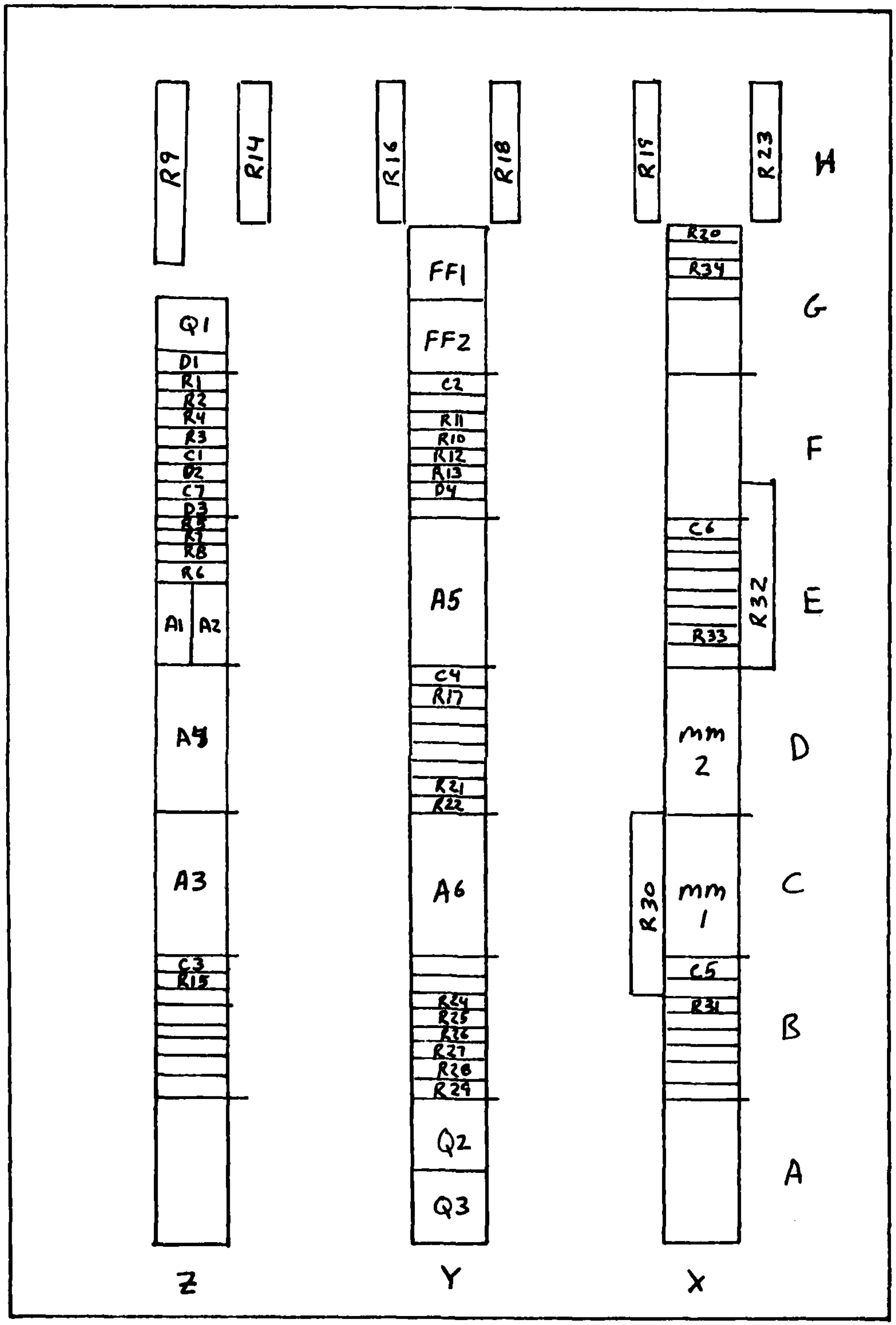


Fig. 22 Pattern Generator Circuit Layout Component Side

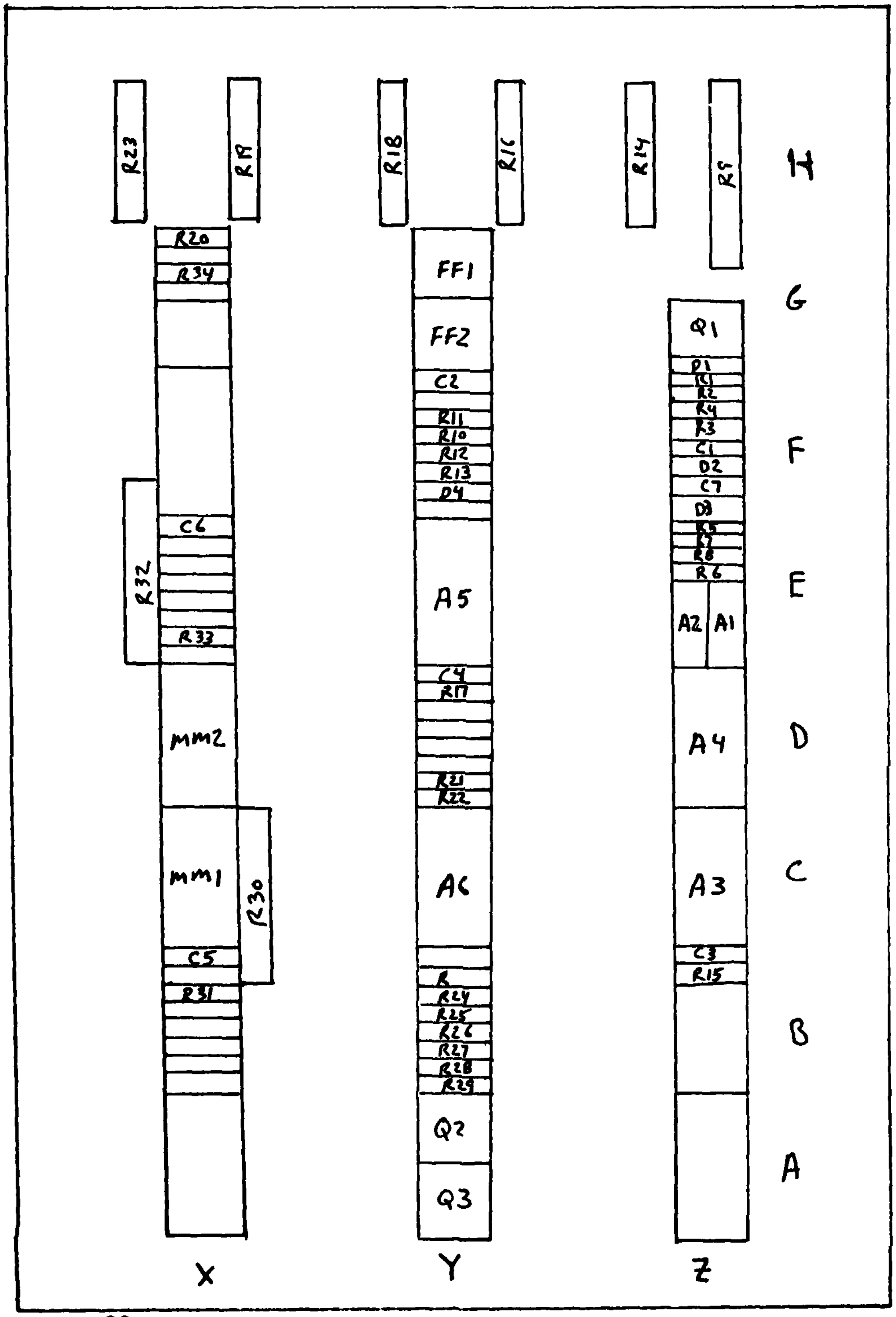


Fig. 23 Pattern Generator Circuit Layout Wiring Side

TABLE II

**Pattern Generator Edge Connector Signals**

| Pin | Signal | Pin | Signal |
|---|---|---|---|
| 1 | | A | + 5 Volts |
| 2 | 9 Volt 60Hz In | B | AC GND |
| 3 | | C | |
| 4 | Vertical Sync Out | D | GND ( V. Sync ) |
| 5 | Adapt Pattern In | E | GND ( Adapt ) |
| 6 | | F | |
| 7 | Test Pattern In | H | GND ( Test ) |
| 8 | | J | + 15 Volts |
| 9 | Contrast DAC In | K | |
| 10 | | L | |
| 11 | | M | |
| 12 | Video Out | N | |
| 13 | | P | |
| 14 | FF #1 J | R | FF #1 K |
| 15 | FF #1 $\bar{Q}$ | S | - 15 Volts |
| 16 | FF #2 Q | T | FF #2 J |
| 17 | | U | FF #2 K |
| 18 | | V | |
| 19 | | W | |
| 20 | | X | - 5 Volts |
| 21 | Horizontal Sync Ref. In | Y | GND ( Horizontal Sync ) |
| 22 | | Z | GND ( System ) |

## Appendix B

### Equipment Operating Procedures

This appendix describes the procedures for operating the automated system to determine the modulation transfer function (MTF) of the human visual system. These procedures are intended for use with the equipment configuration described in appendix A and the computer program contained in appendix E. Any modifications to the equipment or program may require modification of these procedures.

The first step in preparing for an experiment is to insure that all equipment is turned on and has had sufficient time to warm up to provide a stable output. Typically the television line voltage power supplies, the multiplex controller, and the signal generators are left on continuously because of the long warm-up time associated with these items. The television set should be turned on and warm up for from three to five minutes. The teletype and monitor oscilloscopes should also be turned on. The background projector should be turned on and the blackout dot positioned to insure that the background light does not illuminate the grating display.

There are several steps that can be accomplished during the equipment warm-up period. The controls on the pattern generator located adajacent to the display must be set to the proper positions for the test to be accomplished. There are three controls that must be set manually; they are the contrast range switch, the adapt brightness switch and the test brightness switch.

The contrast range switch should be set to position 1, 2, 3, 4 or 5 corresponding to a contrast division of 5, 2, 1, 10 or 20 respectively. The setting depends on the particular test and the subject being tested. Typically switch position 4 (divide by 10) can be used for most tests of subjects with normal vision. The switch setting should be noted for subsequent entry into computer program.

The adapting and test stimulus luminance levels are selected by setting the first two switches of the DIP switch pack.

The line voltage power supply for the television receiver should be checked and adjusted if necessary to be 110 $\pm$ 0.5 volts AC. This voltage can affect the brightness and should be checked during the course of experimentation.

The final check to be made before returning to the operators station is a brightness check. This is accomplished by observing the red cathode voltage with an oscilloscope. The baseline of the horizontal sweep should be 104 volts for a dim stimulus setting and 36 volts for a bright stimulus setting.

Several checks at the operators station must be completed before the experiment can begin. The teletypewriter can be used to provide the values necessary to drive the multiplex controller during these checks. The acoustic coupler must be set to the "local" position and the teletype set to the "on-line" position. The teletype can now be used to control the equipment with commands of the form XXXNQQ where XXX is the control value, N is the channel of the controller to receive the value and QQ is the command to the controller to load the control value.

The signal generators should be checked to insure that they are turned on and properly connected (see Appendix A, figures 20 and 21). The two Wavetek generators in the adapting grating circuit used in the phase lock mode should be checked for lockup and adjusted if necessary. All three Wavetek Model 186 generators in the adapting circuit should be set to approximately 3.80 with the frequency range switch set to 100 K.

An adapting grating should be displayed on the screen. This is accomplished by entering the command 5003QQ via the teletype keyboard. If the equipment is properly adjusted the adapting grating should be drifting smoothly across the screen. If the motion is not smooth, it can be corrected by adjusting the controls of the adapting signal generators. The frequency, amplitude and phase controls all affect this signal. The operator should become familiar with effect each of these controls has on the signal by adjusting each one while observing the output of the operational amplifier in the adapting signal circuit (see figure 20).

The gate signal input to the test stimulus generator should be checked at this point. The gate pulse should be 47 microseconds. This signal is an inverted version of the horizontal synchronization pulse being fed to the Sony receiver. The length of this pulse can be adjusted slightly by adjusting the frequency of the adapting generator. All three generator frequencies must be adjusted to maintain phase lock. If the gate pulse is off by more than a few microseconds, the horizontal synchronization pulse generator in the pattern generator circuit will have to be adjusted to obtain the required 47 microseconds while maintaining the correct adapting grating frequency (see figure 21).

If an adapting grating is to be used, the adapting signal amplitude should be adjusted for the luminance level being used (see Appendix D) . For a 0.2 contrast adapting grating the amplitude should be 0.8 volts for a bright luminance adapting grating or 0.24 volts for a dim luminance grating.

If a stationary rather than a drifting grating is required, the horizontal synchronization reference line should be moved to the "TTL pulse out" terminal on the final output Wavetek generator. (see Appendix A, figure 20).

The final checks to be made are for the test grating. An oscilloscope should be connected to the output of the test generator and the amplitude adjusted to 1.0 volts peak-to-peak. Also a check of the spatial frequency should be made. When the control word 0052QQ is entered a 2 cycle per degree grating should appear on the screen. The frequency vernier should be adjusted to insure that the frequency is exactly 2 cycles/degree. Spatial frequencies 3 thru 10 should also be checked by entering the DAC control values from Table III in Appendix C for each frequency. These values are entered by typing XXX2QQ where XXX is the value from Table III.

This completes the equipment checks. The acoustic coupler should now be placed in the "half duplex" position, and a link should be established with the ASD computer, following normal intercom login procedures. Once this is completed, the MTF computer program can be attached and the experiment started.

A complied version of the MTF computer program in Appendix E is required to control the equipment, and should be attached following standard intercom procedures. In addition to this the CALCOMP plot routines stored in the ASD computer system under the name CCAUX must also be attached. A typical login and execution sequence is shown in figure 24. User entries are underlined for identification. The MTF program provides prompting for all user inputs.

Once the data input phase of the program has been completed and verified by the operator the test begins. The subject requests a stimulus by pushing the stimulus request button (HRB). He then enters his response by pushing the appropriate button on the hand-held response box. (The last two buttons on the bottom row of the HRB are used to enter the subject's response. These two buttons produce a ";" and a "?" and correspond to "period 1" and "period 2" respectively.) The subject then waits for the computers response before requesting the next stimulus.

The operator has the option to continue or stop the program at the end of each test sequence. The operator can also abort the current test at any time by typing a "Q" on the teletype in place of the subject's response. After stopping the program, the operator should route the data plots to the AFIT terminal CALCOMP plotter following standard intercom routing procedures.

```
RIGHT OF IIY TEST PATTERN?
ENTER ... (F7.0): ...

* *** TEST EXECUTION ***
```

Fig. 24 Sample LOGIN and Program Execution

# Appendix C

## Spatial Frequency Calibration Data

This appendix contains the information required to produce the specific spatial frequency gratings for both the adapting and test stimulus. The ability to consistantly produce these gratings is vital to the accuracy of the experimental results. The values in Table III are used in the computer program to control the test grating frequency via the VCG input to the Wavetek Model 186 5 MHz phase lock generator used to produce the test grating signal.

Table III

Spatial Frequency Calibration Data

| Spatial Frequency | DAC #2 Input |
|---|---|
| 2 | 005 |
| 3 | 060 |
| 4 | 115 |
| 5 | 170 |
| 6 | 235 |
| 7 | 295 |
| 8 | 355 |
| 9 | 415 |
| 10 | 475 |

## Appendix D

### Contrast Calabration Data

This appendix contains the contrast calibration data used in this study. Figure 25 shows the relation between the red cathode voltage and the display contrast. The contrast values were determined by measuring the luminance levels using a model 1980 Pritchard Photometer and the formula described in section I.

Tables IV thru XII contain the test stimulus contrast calibration values for 2 thru 10 cycles per degree respectively. The DAC input values are those values required to produce the indicated contrast with a 1 volt peak-to-peak input signal, the contrast level switch set to position 2, and a bright screen luminance. Table XIII shows the contrast sensitivity values for each of the 5 possible switch positions and the 2 possible brightness levels.

A contrast of 0.2 was used for the adapting stimulus. The adapting signal peak-to-peak input voltages required to produce this contrast for a 6 CPD adapting grating are 0.8 volts at 35.0 FL and 0.24 volts at 3.50 FL. These values were determined experimentally by adjusting the adapting signal generator amplitude to produce the required red cathode voltage as determined from figure 25.

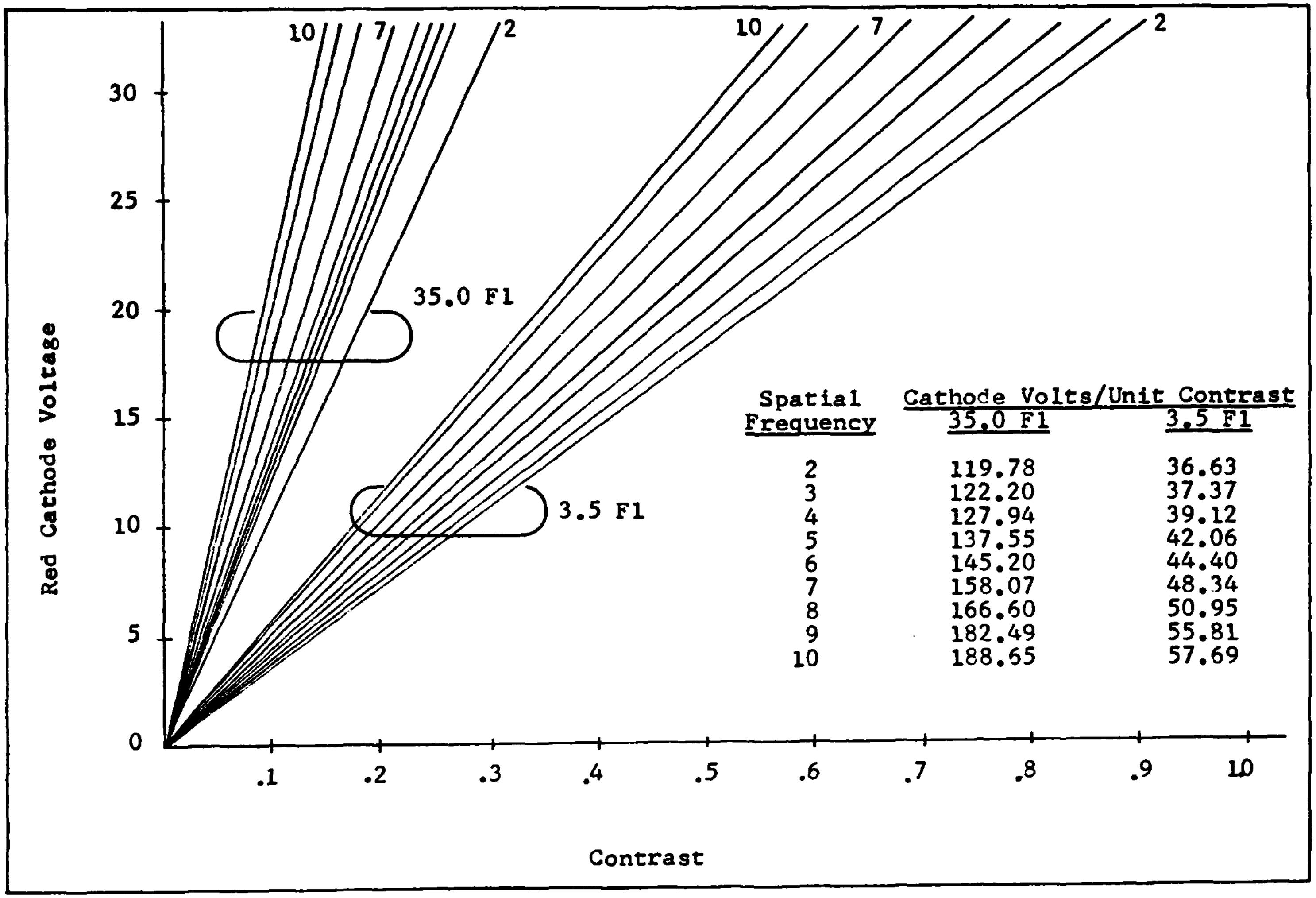


Fig. 25 Red Cathode Voltage vs Contrast for 2 thru 10 cycles/degree

TABLE IV

CONTRAST CALIBRATION DATA: 2 CYCLES/DEGREE

| CONTRAST STEP | LOG CONTRAST | CONTRAST | CONTRAST SENSITIVITY | RED CATHODE VOLTS P-P | DAC DRIVE |
|---|---|---|---|---|---|
| 1 | - .90 | .126 | 7.9 | 13.44 | 614 |
| 2 | - .95 | .112 | 8.9 | 11.98 | 604 |
| 3 | -1.00 | .100 | 10.0 | 10.68 | 593 |
| 4 | -1.05 | .089 | 11.2 | 9.51 | 583 |
| 5 | -1.10 | .079 | 12.6 | 8.48 | 574 |
| 6 | -1.15 | .071 | 14.1 | 7.56 | 566 |
| 7 | -1.20 | .063 | 15.9 | 6.74 | 560 |
| 8 | -1.25 | .056 | 17.8 | 6.00 | 554 |
| 9 | -1.30 | .050 | 20.0 | 5.35 | 548 |
| 10 | -1.35 | .045 | 22.2 | 4.77 | 541 |
| 11 | -1.40 | .040 | 25.0 | 4.25 | 537 |
| 12 | -1.45 | .035 | 28.6 | 3.79 | 530 |
| 13 | -1.50 | .032 | 31.2 | 3.33 | 526 |
| 14 | -1.55 | .028 | 35.7 | 3.01 | 521 |
| 15 | -1.60 | .025 | 40.0 | 2.68 | 517 |
| 16 | -1.65 | .022 | 45.4 | 2.39 | 514 |
| 17 | -1.70 | .020 | 50.0 | 2.13 | 511 |
| 18 | -1.75 | .018 | 55.5 | 1.90 | 507 |
| 19 | -1.80 | .016 | 62.5 | 1.69 | 504 |
| 20 | -1.85 | .014 | 71.4 | 1.51 | 501 |
| 21 | -1.90 | .013 | 76.9 | 1.34 | 497 |
| 22 | -1.95 | .011 | 90.9 | 1.20 | 494 |
| 23 | -2.00 | .010 | 100.0 | 1.07 | 491 |
| 24 | -2.05 | .009 | 111.1 | .95 | 487 |
| 25 | -2.10 | .008 | 125.0 | .85 | 483 |





Fig. 22 Pattern Generator Circuit Layout Component Side

TABLE V

CONTRAST CALIBRATION DATA:    3 CYCLES/DEGREE

| CONTRAST STEP | LOG CONTRAST | CONTRAST | CONTRAST SENSITIVITY | RED CATHODE VOLTS P-P | DAC DRIVE |
|---|---|---|---|---|---|
| 1 | - .90 | .126 | 7.9 | 13.71 | 621 |
| 2 | - .95 | .112 | 8.9 | 12.22 | 610 |
| 3 | -1.00 | .100 | 10.0 | 10.89 | 599 |
| 4 | -1.05 | .089 | 11.2 | 9.71 | 590 |
| 5 | -1.10 | .079 | 12.6 | 8.65 | 582 |
| 6 | -1.15 | .071 | 14.1 | 7.71 | 575 |
| 7 | -1.20 | .063 | 15.9 | 6.87 | 569 |
| 8 | -1.25 | .056 | 17.8 | 6.12 | 562 |
| 9 | -1.30 | .050 | 20.0 | 5.46 | 557 |
| 10 | -1.35 | .045 | 22.2 | 4.86 | 552 |
| 11 | -1.40 | .040 | 25.0 | 4.34 | 545 |
| 12 | -1.45 | .035 | 28.6 | 3.86 | 535 |
| 13 | -1.50 | .032 | 31.2 | 3.44 | 533 |
| 14 | -1.55 | .028 | 35.7 | 3.07 | 528 |
| 15 | -1.60 | .025 | 40.0 | 2.74 | 52[illegible] |
| 16 | -1.65 | .022 | 45.4 | 2.44 | 520 |
| 17 | -1.70 | .020 | 50.0 | 2.17 | 515 |
| 18 | -1.75 | .018 | 55.5 | 1.94 | 513 |
| 19 | -1.80 | .016 | 62.5 | 1.73 | 511 |
| 20 | -1.85 | .014 | 71.4 | 1.54 | 506 |
| 21 | -1.90 | .013 | 76.9 | 1.37 | 499 |
| 22 | -1.95 | .011 | 90.9 | 1.22 | 497 |
| 23 | -2.00 | .010 | 100.0 | 1.09 | 495 |
| 24 | -2.05 | .009 | 111.1 | .97 | 491 |
| 25 | -2.10 | .008 | 125.0 | .87 | 489 |



Fig. 23 Pattern Generator Circuit Layout Wiring Side

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TABLE VI

CONTRAST CALIBRATION DATA: 4 CYCLES/DEGREE

| CONTRAST STEP | LOG CONTRAST | CONTRAST | CONTRAST SENSITIVITY | RED CATHODE VOLTS P-P | DAC DRIVE |
|---|---|---|---|---|---|
| 1 | - .90 | .126 | 7.9 | 14.36 | 630 |
| 2 | - .95 | .112 | 8.9 | 12.79 | 620 |
| 3 | -1.00 | .100 | 10.0 | 11.40 | 611 |
| 4 | -1.05 | .089 | 11.2 | 10.16 | 603 |
| 5 | -1.10 | .079 | 12.6 | 9.06 | 554 |
| 6 | -1.15 | .071 | 14.1 | 8.07 | 583 |
| 7 | -1.20 | .063 | 15.9 | 7.19 | 577 |
| 8 | -1.25 | .056 | 17.8 | 6.41 | 570 |
| 9 | -1.30 | .050 | 20.0 | 5.71 | 564 |
| 10 | -1.35 | .045 | 22.2 | 5.09 | 557 |
| 11 | -1.40 | .040 | 25.0 | 4.54 | 551 |
| 12 | -1.45 | .035 | 28.6 | 4.05 | 545 |
| 13 | -1.50 | .032 | 31.2 | 3.61 | 538 |
| 14 | -1.55 | .028 | 35.7 | 3.21 | 535 |
| 15 | -1.60 | .025 | 40.0 | 2.86 | 529 |
| 16 | -1.65 | .022 | 45.4 | 2.55 | 524 |
| 17 | -1.70 | .020 | 50.0 | 2.29 | 519 |
| 18 | -1.75 | .018 | 55.5 | 2.03 | 515 |
| 19 | -1.80 | .016 | 62.5 | 1.81 | 512 |
| 20 | -1.85 | .014 | 71.4 | 1.61 | 508 |
| 21 | -1.90 | .013 | 76.9 | 1.44 | 504 |
| 22 | -1.95 | .011 | 90.9 | 1.28 | 500 |
| 23 | -2.00 | .010 | 100.0 | 1.14 | 496 |
| 24 | -2.05 | .009 | 111.1 | 1.02 | 490 |
| 25 | -2.10 | .008 | 125.0 | .91 | 486 |

TABLE VII

CONTRAST CALIBRATION DATA: 5 CYCLES/DEGREE

| CONTRAST STEP | LOG CONTRAST | CONTRAST | CONTRAST SENSITIVITY | RED CATHODE VOLTS P-P | DAC DRIVE |
|---|---|---|---|---|---|
| 1 | - .90 | .126 | 7.9 | 15.43 | 644 |
| 2 | - .95 | .112 | 8.9 | 13.76 | 632 |
| 3 | -1.00 | .100 | 10.0 | 12.26 | 622 |
| 4 | -1.05 | .089 | 11.2 | 10.93 | 613 |
| 5 | -1.10 | .079 | 12.6 | 9.74 | 605 |
| 6 | -1.15 | .071 | 14.1 | 8.68 | 597 |
| 7 | -1.20 | .063 | 15.9 | 7.74 | 588 |
| 8 | -1.25 | .056 | 17.8 | 6.89 | 580 |
| 9 | -1.30 | .050 | 20.0 | 6.14 | 573 |
| 10 | -1.35 | .045 | 22.2 | 5.48 | 566 |
| 11 | -1.40 | .040 | 25.0 | 4.88 | 559 |
| 12 | -1.45 | .035 | 28.6 | 4.35 | 553 |
| 13 | -1.50 | .032 | 31.2 | 3.88 | 546 |
| 14 | -1.55 | .028 | 35.7 | 3.46 | 539 |
| 15 | -1.60 | .025 | 40.0 | 3.08 | 534 |
| 16 | -1.65 | .022 | 45.4 | 2.74 | 528 |
| 17 | -1.70 | .020 | 50.0 | 2.45 | 523 |
| 18 | -1.75 | .018 | 55.5 | 2.18 | 519 |
| 19 | -1.80 | .016 | 62.5 | 1.94 | 515 |
| 20 | -1.85 | .014 | 71.4 | 1.73 | 511 |
| 21 | -1.90 | .013 | 76.9 | 1.54 | 507 |
| 22 | -1.95 | .011 | 90.9 | 1.38 | 503 |
| 23 | -2.00 | .010 | 100.0 | 1.23 | 501 |
| 24 | -2.05 | .009 | 111.1 | 1.09 | 493 |
| 25 | -2.10 | .008 | 125.0 | .97 | 488 |

## TABLE VIII

CONTRAST CALIBRATION DATA: 6 CYCLES/DEGREE

| CONTRAST STEP | LOG CONTRAST | CONTRAST | CONTRAST SENSITIVITY | RED CATHODE VOLTS P-P | DAC DRIVE |
|---|---|---|---|---|---|
| 1 | - .90 | .126 | 7.9 | 16.29 | 667 |
| 2 | - .95 | .112 | 8.9 | 14.52 | 650 |
| 3 | -1.00 | .100 | 10.0 | 12.94 | 637 |
| 4 | -1.05 | .089 | 11.2 | 11.53 | 626 |
| 5 | -1.10 | .079 | 12.6 | 10.28 | 615 |
| 6 | -1.15 | .071 | 14.1 | 9.16 | 605 |
| 7 | -1.20 | .063 | 15.9 | 8.17 | 597 |
| 8 | -1.25 | .056 | 17.8 | 7.28 | 589 |
| 9 | -1.30 | .050 | 20.0 | 6.49 | 581 |
| 10 | -1.35 | .045 | 22.2 | 5.78 | 573 |
| 11 | -1.40 | .040 | 25.0 | 5.15 | 565 |
| 12 | -1.45 | .035 | 28.6 | 4.59 | 558 |
| 13 | -1.50 | .032 | 31.2 | 4.09 | 552 |
| 14 | -1.55 | .028 | 35.7 | 3.65 | 545 |
| 15 | -1.60 | .025 | 40.0 | 3.25 | 539 |
| 16 | -1.65 | .022 | 45.4 | 2.90 | 533 |
| 17 | -1.70 | .020 | 50.0 | 2.58 | 528 |
| 18 | -1.75 | .018 | 55.5 | 2.30 | 523 |
| 19 | -1.80 | .016 | 62.5 | 2.05 | 519 |
| 20 | -1.85 | .014 | 71.4 | 1.83 | 515 |
| 21 | -1.90 | .013 | 76.9 | 1.63 | 511 |
| 22 | -1.95 | .011 | 90.9 | 1.45 | 507 |
| 23 | -2.00 | .010 | 100.0 | 1.29 | 503 |
| 24 | -2.05 | .009 | 111.1 | 1.15 | 499 |
| 25 | -2.10 | .008 | 125.0 | 1.03 | 495 |

TABLE IX

CONTRAST CALIBRATION DATA: 7 CYCLES/DEGREE

| CONTRAST STEP | LOG CONTRAST | CONTRAST | CONTRAST SENSITIVITY | RED CATHODE VOLTS P-P | DAC DRIVE |
|---|---|---|---|---|---|
| 1 | - .90 | .126 | 7.9 | 17.74 | 695 |
| 2 | - .95 | .112 | 8.9 | 15.81 | 675 |
| 3 | -1.00 | .100 | 10.0 | 14.09 | 657 |
| 4 | -1.05 | .089 | 11.2 | 12.56 | 644 |
| 5 | -1.10 | .079 | 12.6 | 11.19 | 631 |
| 6 | -1.15 | .071 | 14.1 | 9.97 | 619 |
| 7 | -1.20 | .063 | 15.9 | 8.89 | 609 |
| 8 | -1.25 | .056 | 17.8 | 7.92 | 599 |
| 9 | -1.30 | .050 | 20.0 | 7.06 | 591 |
| 10 | -1.35 | .045 | 22.2 | 6.29 | 582 |
| 11 | -1.40 | .040 | 25.0 | 5.61 | 574 |
| 12 | -1.45 | .035 | 28.6 | 5.00 | 567 |
| 13 | -1.50 | .032 | 31.2 | 4.46 | 560 |
| 14 | -1.55 | .028 | 35.7 | 3.97 | 554 |
| 15 | -1.60 | .025 | 40.0 | 3.54 | 547 |
| 16 | -1.65 | .022 | 45.4 | 3.15 | 541 |
| 17 | -1.70 | .020 | 50.0 | 2.81 | 536 |
| 18 | -1.75 | .018 | 55.5 | 2.51 | 531 |
| 19 | -1.80 | .016 | 62.5 | 2.23 | 526 |
| 20 | -1.85 | .014 | 71.4 | 1.99 | 521 |
| 21 | -1.90 | .013 | 76.9 | 1.77 | 518 |
| 22 | -1.95 | .011 | 90.9 | 1.58 | 514 |
| 23 | -2.00 | .010 | 100.0 | 1.41 | 510 |
| 24 | -2.05 | .009 | 111.1 | 1.26 | 507 |
| 25 | -2.10 | .008 | 125.0 | 1.12 | 503 |

TABLE X

CONTRAST CALIBRATION DATA: 8 CYCLES/DEGREE

| CONTRAST STEP | LOG CONTRAST | CONTRAST | CONTRAST SENSITIVITY | RED CATHODE VOLTS P-P | DAC DRIVE |
|---|---|---|---|---|---|
| 1 | - .90 | .126 | 7.9 | 18.69 | 738 |
| 2 | - .95 | .112 | 8.9 | 16.66 | 705 |
| 3 | -1.00 | .100 | 10.0 | 14.85 | 679 |
| 4 | -1.05 | .089 | 11.2 | 13.23 | 659 |
| 5 | -1.10 | .079 | 12.6 | 11.79 | 645 |
| 6 | -1.15 | .071 | 14.1 | 10.51 | 633 |
| 7 | -1.20 | .063 | 15.9 | 9.37 | 622 |
| 8 | -1.25 | .056 | 17.8 | 8.35 | 611 |
| 9 | -1.30 | .050 | 20.0 | 7.44 | 603 |
| 10 | -1.35 | .045 | 22.2 | 6.63 | 593 |
| 11 | -1.40 | .040 | 25.0 | 5.91 | 583 |
| 12 | -1.45 | .035 | 28.6 | 5.27 | 575 |
| 13 | -1.50 | .032 | 31.2 | 4.70 | 567 |
| 14 | -1.55 | .028 | 35.7 | 4.18 | 560 |
| 15 | -1.60 | .025 | 40.0 | 3.73 | 555 |
| 16 | -1.65 | .022 | 45.4 | 3.32 | 548 |
| 17 | -1.70 | .020 | 50.0 | 2.96 | 542 |
| 18 | -1.75 | .018 | 55.5 | 2.64 | 538 |
| 19 | -1.80 | .016 | 62.5 | 2.35 | 529 |
| 20 | -1.85 | .014 | 71.4 | 2.10 | 525 |
| 21 | -1.90 | .013 | 76.9 | 1.87 | 521 |
| 22 | -1.95 | .011 | 90.9 | 1.67 | 517 |
| 23 | -2.00 | .010 | 100.0 | 1.48 | 513 |
| 24 | -2.05 | .009 | 111.1 | 1.32 | 509 |
| 25 | -2.10 | .008 | 125.0 | 1.18 | 506 |

TABLE XI

CONTRAST CALIBRATION DATA: 9 CYCLES/DEGREE

| CONTRAST STEP | LOG CONTRAST | CONTRAST | CONTRAST SENSITIVITY | RED CATHODE VOLTS P-P | DAC DRIVE |
|---|---|---|---|---|---|
| 1 | - .90 | .126 | 7.9 | 20.48 | 814 |
| 2 | - .95 | .112 | 8.9 | 18.25 | 756 |
| 3 | -1.00 | .100 | 10.0 | 16.26 | 710 |
| 4 | -1.05 | .089 | 11.2 | 14.50 | 690 |
| 5 | -1.10 | .079 | 12.6 | 12.92 | 675 |
| 6 | -1.15 | .071 | 14.1 | 11.51 | 660 |
| 7 | -1.20 | .063 | 15.9 | 10.26 | 647 |
| 8 | -1.25 | .056 | 17.8 | 9.15 | 634 |
| 9 | -1.30 | .050 | 20.0 | 8.15 | 622 |
| 10 | -1.35 | .045 | 22.2 | 7.27 | 611 |
| 11 | -1.40 | .040 | 25.0 | 6.47 | 601 |
| 12 | -1.45 | .035 | 28.6 | 5.77 | 591 |
| 13 | -1.50 | .032 | 31.2 | 5.14 | 581 |
| 14 | -1.55 | .028 | 35.7 | 4.58 | 572 |
| 15 | -1.60 | .025 | 40.0 | 4.09 | 565 |
| 16 | -1.65 | .022 | 45.4 | 3.64 | 557 |
| 17 | -1.70 | .020 | 50.0 | 3.25 | 551 |
| 18 | -1.75 | .018 | 55.5 | 2.89 | 543 |
| 19 | -1.80 | .016 | 62.5 | 2.58 | 538 |
| 20 | -1.85 | .014 | 71.4 | 2.30 | 532 |
| 21 | -1.90 | .013 | 76.9 | 2.05 | 527 |
| 22 | -1.95 | .011 | 90.9 | 1.82 | 522 |
| 23 | -2.00 | .010 | 100.0 | 1.63 | 518 |
| 24 | -2.05 | .009 | 111.1 | 1.45 | 514 |
| 25 | -2.10 | .008 | 125.0 | 1.29 | 510 |

TABLE XII

CONTRAST CALIBRATION DATA: 10 CYCLES/DEGREE

| CONTRAST STEP | LOG CONTRAST | CONTRAST | CONTRAST SENSITIVITY | RED CATHODE VOLTS P-P | DAC DRIVE |
|---|---|---|---|---|---|
| 1 | - .90 | .126 | 7.9 | 21.17 | 922 |
| 2 | - .95 | .112 | 8.9 | 18.87 | 805 |
| 3 | -1.00 | .100 | 10.0 | 16.81 | 750 |
| 4 | -1.05 | .089 | 11.2 | 14.99 | 714 |
| 5 | -1.10 | .079 | 12.6 | 13.36 | 691 |
| 6 | -1.15 | .071 | 14.1 | 11.90 | 674 |
| 7 | -1.20 | .063 | 15.9 | 10.61 | 660 |
| 8 | -1.25 | .056 | 17.8 | 9.45 | 646 |
| 9 | -1.30 | .050 | 20.0 | 8.43 | 633 |
| 10 | -1.35 | .045 | 22.2 | 7.51 | 621 |
| 11 | -1.40 | .040 | 25.0 | 6.69 | 609 |
| 12 | -1.45 | .035 | 28.6 | 5.97 | 599 |
| 13 | -1.50 | .032 | 31.2 | 5.32 | 590 |
| 14 | -1.55 | .028 | 35.7 | 4.74 | 581 |
| 15 | -1.60 | .025 | 40.0 | 4.22 | 572 |
| 16 | -1.65 | .022 | 45.4 | 3.76 | 563 |
| 17 | -1.70 | .020 | 50.0 | 3.35 | 556 |
| 18 | -1.75 | .018 | 55.5 | 2.99 | 550 |
| 19 | -1.80 | .016 | 62.5 | 2.66 | 544 |
| 20 | -1.85 | .014 | 71.4 | 2.37 | 536 |
| 21 | -1.90 | .013 | 76.9 | 2.12 | 530 |
| 22 | -1.95 | .011 | 90.9 | 1.89 | 526 |
| 23 | -2.00 | .010 | 100.0 | 1.68 | 522 |
| 24 | -2.05 | .009 | 111.1 | 1.50 | 518 |
| 25 | -2.10 | .008 | 125.0 | 1.34 | 514 |

TABLE XIII

Contrast Sensitivity For Contrast Range Switch Setting
1 thru 5 and Both Bright and Dim Luminance Levels

| Contrast Range Switch Setting: | 1 | | 2 | | 3 | | 4 | | 5 | |
|---|---|---|---|---|---|---|---|---|---|---|
| Luminance: | Bright | Dim | Bright | Dim | Bright | Dim | Bright | Dim | Bright | Dim |
| Contrast Step | | | | | | | | | | |
| 1 | 17.1 | 5.2 | 7.9 | 2.4 | 4.0 | 1.2 | 37.1 | 11.3 | 66.5 | 20.3 |
| 2 | 19.2 | 5.9 | 8.9 | 2.7 | 4.5 | 1.4 | 41.7 | 12.7 | 74.7 | 22.8 |
| 3 | 21.5 | 6.6 | 10.0 | 3.0 | 5.1 | 1.5 | 46.8 | 14.3 | 84.2 | 25.7 |
| 4 | 24.3 | 7.4 | 11.2 | 3.4 | 5.7 | 1.7 | 52.8 | 16.1 | 94.9 | 28.9 |
| 5 | 27.1 | 8.3 | 12.6 | 3.8 | 6.4 | 1.9 | 58.9 | 18.0 | 105.9 | 32.3 |
| 6 | 30.5 | 9.3 | 14.1 | 4.3 | 7.2 | 2.2 | 66.1 | 20.2 | 118.8 | 36.3 |
| 7 | 34.0 | 10.4 | 15.9 | 4.9 | 8.0 | 2.4 | 74.1 | 22.6 | 133.2 | 40.7 |
| 8 | 38.3 | 11.7 | 17.8 | 5.4 | 9.0 | 2.8 | 83.2 | 25.4 | 149.6 | 45.6 |
| 9 | 43.0 | 13.1 | 20.0 | 6.1 | 10.1 | 3.1 | 93.3 | 28.5 | 167.8 | 51.2 |
| 10 | 48.2 | 14.7 | 22.2 | 6.8 | 11.3 | 3.5 | 104.7 | 31.9 | 188.3 | 57.5 |
| 11 | 54.1 | 16.5 | 25.0 | 7.6 | 12.7 | 3.9 | 117.5 | 35.8 | 211.3 | 64.4 |
| 12 | 60.7 | 18.5 | 28.6 | 8.7 | 14.3 | 4.4 | 131.8 | 40.2 | 237.0 | 72.3 |
| 13 | 68.1 | 20.8 | 31.2 | 9.5 | 16.0 | 4.9 | 147.9 | 45.1 | 266.0 | 81.1 |
| 14 | 76.4 | 23.3 | 35.7 | 10.9 | 18.0 | 5.5 | 165.9 | 50.6 | 298.4 | 91.0 |
| 15 | 85.8 | 26.2 | 40.0 | 12.2 | 20.1 | 6.2 | 186.2 | 56.8 | 334.9 | 102.1 |
| 16 | 96.3 | 29.4 | 45.4 | 13.9 | 22.6 | 6.9 | 208.9 | 64.0 | 375.7 | 115.2 |
| 17 | 108.0 | 32.9 | 50.0 | 15.3 | 25.4 | 7.7 | 234.4 | 71.5 | 421.6 | 128.6 |
| 18 | 121.2 | 37.0 | 55.5 | 16.9 | 28.5 | 8.7 | 263.0 | 80.3 | 473.0 | 144.3 |
| 19 | 136.0 | 41.5 | 62.5 | 19.1 | 32.0 | 9.8 | 295.1 | 90.1 | 530.7 | 162.0 |
| 20 | 152.6 | 46.6 | 71.4 | 21.8 | 35.9 | 10.9 | 331.1 | 101.0 | 595.5 | 181.6 |
| 21 | 171.2 | 52.2 | 76.9 | 23.5 | 40.2 | 12.3 | 371.5 | 113.4 | 668.2 | 203.9 |
| 22 | 192.1 | 58.6 | 90.9 | 27.7 | 45.2 | 13.8 | 416.9 | 127.2 | 749.8 | 228.8 |
| 23 | 215.5 | 65.8 | 100.0 | 30.5 | 50.7 | 15.5 | 467.7 | 142.7 | 841.2 | 256.6 |
| 24 | 241.8 | 73.8 | 111.1 | 33.9 | 56.9 | 17.4 | 524.8 | 160.2 | 943.9 | 288.0 |
| 25 | 271.3 | 82.8 | 125.0 | 38.1 | 63.8 | 19.5 | 588.8 | 179.7 | 1059.0 | 323.2 |

## Appendix E

## MTF Computer Program

This appendix contains a complete listing of the program used to control the equipment used to determine subject's contrast sensitivity to sine wave grating.

```
      PROGRAM MTF(INPUT,OUTPUT,TAPE1,PUNCH,PRINT,TAPE2=PRINT)
*     LAST CHANGE  8 NOV 79
*********************************************************************
*  THIS PROGRAM CONTROLS THE OPERATION OF THE AUTOMATED
*  SYSTEM FOR DETERMINING THE ANISOTROPIC MODULATION
*  TRANSFER FUNCTION OF THE HUMAN VISUAL SYSTEM.
*  THE PROGRAM GENERATES THE CONTROL WORDS NECESSARY
*  TO DRIVE THE MULTIPLEX CONTROLLER TO SET THE CONTRAST OF
*  THE VIDEO SIGNAL AND CONTROL THE FREQUENCY OF THE DISPLAY.
*********************************************************************
      INTEGER CONT(25,10)
      INTEGER DATE,FREQCAL(10)
      DIMENSION PCNTR(27),CNSTSEN(27)
      DIMENSION SCRATCH(1024)
      COMMON/DAC/CONT
      DATA(DELTA=.015625)
      DATA(ADAPT=1H?)
      CALL PLOTS(SCRATCH,1024,1)
*********************************************************************
*  THESE STATEMENTS CONTAIN THE CALIBRATION DATA FOR THE
*  CONTRAST LEVELS FOR EACH SPATIAL FREQUENCY.
*********************************************************************
      DATA((CONT(I,2),I=1,25)=614,604,593,583,574,566,560,554,548,541,
     X537,530,525,521,517,514,511,507,504,501,497,494,491,487,483)
******
      DATA((CONT(I,3),I=1,25)=621,610,600,590,582,575,569,562,557,552,
     X545,535,533,528,523,520,515,513,511,505,499,497,495,491,489)
******
      DATA((CONT(I,4),I=1,25)=630,620,611,603,594,583,574,571,564,557,
```

Fig. 26 MTF Computer Program Listing (page 1 of 10)

```
     X561,545,530,533,529,524,519,515,512,503,504,500,496,493,480)
******
       DATA((CONT(I,5),I=1,25)=644,632,622,613,605,597,589,581,573,566,
     X559,553,546,539,534,528,523,519,515,511,507,503,501,493,483)
******
       DATA((CONT(I,6),I=1,25)=667,650,637,625,615,605,597,583,581,573,
     X565,558,552,545,539,533,528,523,519,515,511,507,503,493,493)
******
       DATA((CONT(I,7),I=1,25)=695,675,657,644,631,619,609,593,591,582,
     X574,567,560,554,547,541,536,531,525,521,518,514,510,507,503)
******
       DATA((CONT(I,8),I=1,25)=738,705,679,653,645,633,622,611,603,593,
     X583,577,567,560,555,548,542,538,529,525,521,517,513,503,506)
******
       DATA((CONT(I,9),I=1,25)=814,755,715,690,675,660,647,634,622,611,
     X601,591,581,572,565,557,551,543,533,532,527,522,518,514,515)
******
       DATA((CONT(I,10),I=1,25)=922,805,736,714,691,674,657,646,633,621,
     X603,599,590,581,572,563,556,550,544,536,530,526,522,513,514)
**************************************************************************
*  FRECAL CONTAINS THE THE DATA TO CONTROL THE VCO VIA DAC #2
**************************************************************************
       DATA((FRECCAL(I),I=1,10)=530,365,550,115,170,235,295,335,415,475)
**************************************************************************
*  INITIALIZE ALL DAC'S.
**************************************************************************
  100 PRINT 105
  105 FORMAT(" 999300  065200  001700  CHECK FREQUENCY LOOKUP OK."/)
**************************************************************************
*  CHECK/CHANGE THE VCO CALIBRATION DATA FOR EACH FREQUENCY.
**************************************************************************
       GO TO 170
  110 PRINT 115
```

Fig. 26  MTF Computer Program Listing (page 2 of 10)

```
  115 FORMAT(1X,"ENTER 10 VALUES FOR FREQ. CAL. ( I3 I3 ETC.) :"/)
      READ 125,(FREQCAL(I),I=1,10)
  125 FORMAT(10I4)
  130 PRINT 135,(FREQCAL(I),I=1,10)
  135 FORMAT(1X,"(FREQCAL(I),I=1,10)=",10I5//1X,"FRECAL OK ? YES OR NO:
     X ")
      READ 145,ANS
  145 FORMAT(A1)
      IF (ANS.EQ.1HN) GO TO 110
**********************************************************************
*  THE ID, DATE, AND STEP SIZE SHOULD BE ENTERED
*  IN THE FOLLOWING FORMAT: A3,A7,I1.
*  ALSO NOTE BRIGHT OR DIM TEST PATTERN: (A2).
**********************************************************************
  150 PRINT 155
  155 FORMAT(1X,"ENTER ID(A3), DATE(A7) :   ")
      READ 165,ID,DATE
  165 FORMAT(A3,A7)
      PRINT 175
175   FORMAT(" BRIGHT OR DIM TEST PATTERN? ")
      READ 185,TEST
  185 FORMAT(A1)
      IF(TEST.EQ.1HD) GO TO 190
      LUMIN=4435.0
      GO TO 200
  190 LUMIN=447.50
  200 PRINT 205
  205 FORMAT(" ENTER TEST STIMULUS DURATION(F4.0): ")
      READ 215,TYME
  215 FORMAT(F4.0)
************************************************************
* SET CONTRAST RANGE
************************************************************
```

Fig. 26  MTF Computer Program Listing (page 3 of 10)

```
      PRINT 225
  225 FORMAT(1X,"RECORD CONTRAST RANGE SWITCH SETTING (A1)  :  ")
      READ 235,SWITCH
  235 FORMAT (A1)
      CONRNG =1.00
      IF (SWITCH.EQ.1H1) CONRNG =2.17
      IF (SWITCH.EQ.1H2) CONRNG =4.73
      IF (SWITCH.EQ.1H3) CONRNG =9.23
      IF (SWITCH.EQ.1H4) CONRNG =1.00
      IF (SWITCH.EQ.1H5) CONRNG =0.556
*************************************************************************
* SCREEN BRIGHT OR DIM BETWEEN TEST STIMULUS ?
*************************************************************************
      PRINT 245
  245 FORMAT(" BRIGHT OR DIM SCREEN BETWEEN STIMULI ? ")
      READ 255,AL
  255 FORMAT(A1)
      IF(AL.EQ.1HB) ADLUM=AH3.0
      IF(AL.EQ.1HD) ADLUM=AH3.50
*************************************************************************
*  ADAPTING PATTERN OR BLANK SCREEN BETWEEN TEST STIMULI ?
*************************************************************************
      ADAPT=1HP
      DRIFT=3H
       PRINT 305
  305 FORMAT(" ADAPTING PATTERN OR BLANK SCREEN? ")
      READ 315,SELECT
  315 FORMAT(A1)
      IF(1HA.EQ.SELECT) GO TO 320
      IF (1HB.EQ.SELECT) GO TO 350
  320 PRINT 325
  325 FORMAT(" FDC300  -  SET ADAPTING PATTERN SIGNAL GENERATOR"/
     X1X,"RECORD ADAPTING PATTERN FREQUENCY (A1) : ")
```

Fig. 26 MTF Computer Program Listing (page 4 of 10)

```
      READ 335,ADAPT
  335 FORMAT(A1)
      PRINT  345
  345 FORMAT(" DRIFTING OR FIXED? ")
      READ 335,MOVE
      IF(MOVE.EQ.1HD) DRIFT=9H DRIFTING
      GO TO 350
  350 PRINT 355
  355 FORMAT(" 030300  -  BLANK SCREEN BETWEEN TEST STIMULI"//)
  360 CONTINUE
***********************************************************************
*  DETERMINE CONTRAST STEP VALUES
***********************************************************************
C  JNUM IS MAX NUMBER OF CONTRAST STEPS
      JNUM=5
      PRINT 415
415   FORMAT(" ENTER CONTRAST STEP SIZE(I2): ")
      READ 405,JSTEP
  405 FORMAT(I2)
      PRINT 425
425   FORMAT(" ENTER NUMBER OF TRIALS AT EACH CONTRAST LEVEL(I2): ")
      READ 405,KSTOP
**********************************************************************
*  VERIFICATION OF INPUT DATA. IF THE INPUT DATA DOES NOT DESCRIBE THE
*  TEST PARAMETERS , REACCOMPLISH TEST DESCRIPTION.
***********************************************************************
430   PRINT 435,ID,DATE,ADAPT,ALUM,LUMIN,JNUM,JSTEP,KSTOP
435   FORMAT(" SUBJECT: ",A3,/," DATE: ",A7,/," A.F.:        ",A1,"  AT "
     X,A4," FL ",/," T.F.:          AT ",A4," FL ",/," ",I2,"
     XCONTRAST LEVELS OF SIZE: ",I2,/," ",I2," TRIALS AT EACH LEVEL",//,
     X" IS ALL DATA OK? (YES OR NO): ")
      READ  445,INPUT
  445 FORMAT (A1)
```

**Fig. 26  MTF Computer Program Listing (page 5 of 10)**

```
      R=TIME(1)
      CALL RANSET(R)
      IF(INPUT.EQ.1HN) GO TO 150
******************************************************************
*  REQUEST TEST FREQUENCY AND IF NOT A WHOLE NUMBER CALCULATE
*  FREQUENCY AND CONTRAST CALIBRATION DATA.
******************************************************************
 450  CONTINUE
      PRINT 455
 455  FORMAT(//" ENTER TEST FREQ(F4.2):")
      READ*,FREQ
      IF(FREQ.LT.2) GO TO 750
      IF(FREQ.GT.10) GO TO 750
      IFREQ=1
 460  CONTINUE
      IFREQ=IFREQ+1
      IF(FLOAT(IFREQ).EQ.FREQ) GO TO 480
      IF(FLOAT(IFREQ).LT.FREQ) GO TO 460
      FDIFF=FLOAT(FREQCAL(IFREQ)-FREQCAL(IFREQ-1))
      FREQCAL(1)=FREQCAL(IFREQ-1)+IFIX(FDIFF*(FREQ-FLOAT(IFREQ-1)))
      DO 470 IK=1,25
      CDIFF=FLOAT(CONT(IK,IFREQ)-CONT(IK,IFREQ-1))
      CONT(IK,1)=CONT(IK,IFREQ-1)+IFIX(CDIFF*(FREQ-FLOAT(IFREQ-1)))
 470  CONTINUE
      IFREQ=1
 480  CONTINUE
      I=IFREQ
******************************************************************
*  BEGIN ORIENTATION RUN - FIND APPROX CONTRAST THRESHOLD
******************************************************************
      PRINT 510,FREQCAL(1)
 510  FORMAT(" ",I3,"200 ")
 520  II=1
```

Fig. 26 MTF Computer Program Listing (page 6 of 10)

```
  171 II=II+5
      NRT=1
  173 CALL STIMULS(II,I,640,ANSWER),
     XRETURNS(620)
      IF(ANSWER.EQ.1HW)GO TO 600
      NRT=NRT+1
      IF(NRT.LE.3)GO TO 173
      GO TO 171
*****************************************************************************
*   BEGIN MAIN RUN
*****************************************************************************
  600 N=0
      KK=0
      J=II-2
      JSTOP=J+JNUM*JSTEP
  620 CONTINUE
      IF (J.LE.0) J=1
      IF (J.GT.25) J=25
      NRIGHT=NWRONG=0
      N=N+1
      K=1
  630 CONTINUE
      CALL STIMULS(J,I,640,ANSWER),
     XRETURNS(670)
      K=K+1
      IF(ANSWER.EQ.1HR) NRIGHT=NRIGHT+1
      IF(N.NE.1) GO TO 640
      IF(FLOAT(NRIGHT).LE.(0.8*K)) GO TO 660
  640 IF(K.GE.KSTOP) 650,630
  650 CONTINUE
      RIGHT=FLOAT(NRIGHT)
      PCNTR(N)=(RIGHT/KSTOP)*100.0
      IF(N.NE.1) GO TO 680
```

Fig. 26 MTF Computer Program Listing (page 7 of 10)

```
      IF(PONTR(N).GE.99.00) GO TO 680
  660 N=0
      J=J-2
      JSTOP=JSTOP-2
      GO TO 620
  670 N=N-1
      GO TO 710
  680 CNSTSEN(N)=1/((10**(-1.52-0.03*J))*CONRNG)
      IF(TEST.EQ.1HD) CNSTSEN(N)=CNSTSEN(N)/(10.*DELTA)
      IF(PONTR(N).LE.50.00) J=JSTOP
      J=J+JSTEP
      IF(J.LE.JSTOP) GO TO 620
************************************************************************
************************************************************************
  700 IF(N.LE.1) GO TO 750
      CALL PLOT(3.5,-12.0,-3)
      CALL PLOT(0.0,3.0,-3)
      SIZE=((CNSTSEN(N)-CNSTSEN(1))/10.0)+2.0
      PASTG=SIZE+2.0
      PONTR(N+1)=0.0
      PONTR(N+2)=16.667
      CALL SCALE(CNSTSEN,SIZE,N,1)
      CALL AXIS(0.0,0.0,20HCONTRAST SENSITIVITY,-20,SIZE,0.0,CNSTSEN(N+1
     X),CNSTSEN(N+2))
      CALL AXIS(0.0,0.0,9H% CORRECT,9,5.0,90.0,PONTR(N+1),PONTR(N+2))
      CALL FLINE(CNSTSEN,PONTR,N,1,1,135)
      CALL SYMBOL(0.0,-1.0,0.12,9HSUBJECT: ,0.0,9)
      CALL SYMBOL(999.,999.,0.12,ID,0.0,3)
      CALL SYMBOL(999.,999.,0.12,9H    DATE: ,0.0,9)
      CALL SYMBOL(999.,999.,0.12,DATE,0.0,7)
      CALL SYMBOL(0.0,-1.3,0.12,6HA.F.: ,0.0,6)
      CALL SYMBOL(999.,999.,0.12,ADAPT,0.0,1)
      CALL SYMBOL(999.,999.,0.12,8H CPD AT ,0.0,8)
```

Fig. 26  MTF Computer Program Listing (page 8 of 10)

```
      CALL SYMBOL(999.,999.,0.12,ADLUM,0.0,5)
      CALL SYMBOL(999.,999.,0.12,3H FL,0.0,3)
      CALL SYMBOL(0.0,-1.5,0.12,6HT.F.: ,0.0,6)
      CALL NUMBER(999.,999.,0.12,FREQ,0.0,2)
      CALL SYMBOL(999.,999.,0.12,8H CPD AT ,0.0,8)
      CALL SYMBOL(999.,999.,0.12,LUMIN,0.0,5)
      CALL SYMBOL(999.,999.,0.12,3H FL,0.0,3)
      CALL SYMBOL(0.0,-1.9,0.12,18HSTIMULUS DURATION: ,0.0,18)
      CALL NUMBER(999.,999.,0.12,TYME,0.0,-1)
      CALL SYMBOL(999.,999.,0.12,5H MSEC,0.0,5)
      CALL PLOT(PASTG,0.0,-3)
      GO TO 450
  750 CONTINUE
**************************************************************************
*
*  CONTINUE OR STOP ?
*
**************************************************************************
805   PRINT 805
805   FORMAT(" 22(700    TYPE CONTINUE OR STOP ? ")
      READ 815,INTENT
815   FORMAT(A1)
      IF(INTENT.EQ.1HC)GO TO 820
      IF(INTENT.EQ.1HS)GO TO 800
820   CONTINUE
**************************************************************************
*
* DETERMINE WHAT IF ANY TEST PARAMETERS ARE TO BE CHANGED
*
**************************************************************************
      GO TO 430
**************************************************************************
*
```

Fig. 26  MTF Computer Program Listing (page 9 of 10)

```
* STOP PROGRAM
*
*****************************************************************************
900   PRINT 905
905   FORMAT(" 031700 155200 999100 001300 ROUTE FILES TO AFIT")
      CALL PLOTE(1)
      STOP
      END
*****************************************************************************
*
*
*****************************************************************************
      SUBROUTINE STIMULS(LEVEL,IFREQ,STATUS,RESPOND),
     XRETURNS(MM)
      COMMON/DAC/CONTRST(25,10)
      RNUM=RANF(RNU)
      IF(RNUM.LT.0.5)1000,1010
1000  IFRAME=0
      FRAME=1H2
      GO TO 1020
1010  IFRAME=1
      FRAME=1H1
1020  CONTINUE
      PRINT 1030,IFRAME,CONTRST(LEVEL,IFREQ),STATUS,FRAME
1030  FORMAT(" 00",I1,"000    ",I3,"000    ",I3,"000    ",A1,1X)
      READ 1040,REPLY
1040  FORMAT(A1)
      IF(REPLY.EQ.1H0) GO TO 1050
      RESPOND=1HW
      IF(REPLY.EQ.FRAME) RESPOND=1HR
      RETURN
1050  RETURN MM
      END
```

Fig. 26  MTF Computer Program Listing (page 10 of 10)

AD-A080 421 AIR FORCE INST OF TECH WRIGHT-PATTERSON AFB OH SCHOO--ETC F/G 6/16
AN EXPERIMENTAL STUDY OF SPATIAL FREQUENCY ADAPTATION EFFECTS I--ETC(U)
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2 OF 2
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# Appendix F

## Individual Data Plots

This appendix contains a complete listing of each individual test that was completed for each subject. The plots are arranged by subject and date with the exception of subject MJK. Because of the large number of plots for subject MJK they are subdivided into the four possible adapt-test stimulus luminance combinations: Bright-Bright, Dim-Dim, Dim-Bright and Bright-Dim. The plots are then arranged by date within these sections.

SUBJECT: MJK

Adapt: Bright

Test: Bright

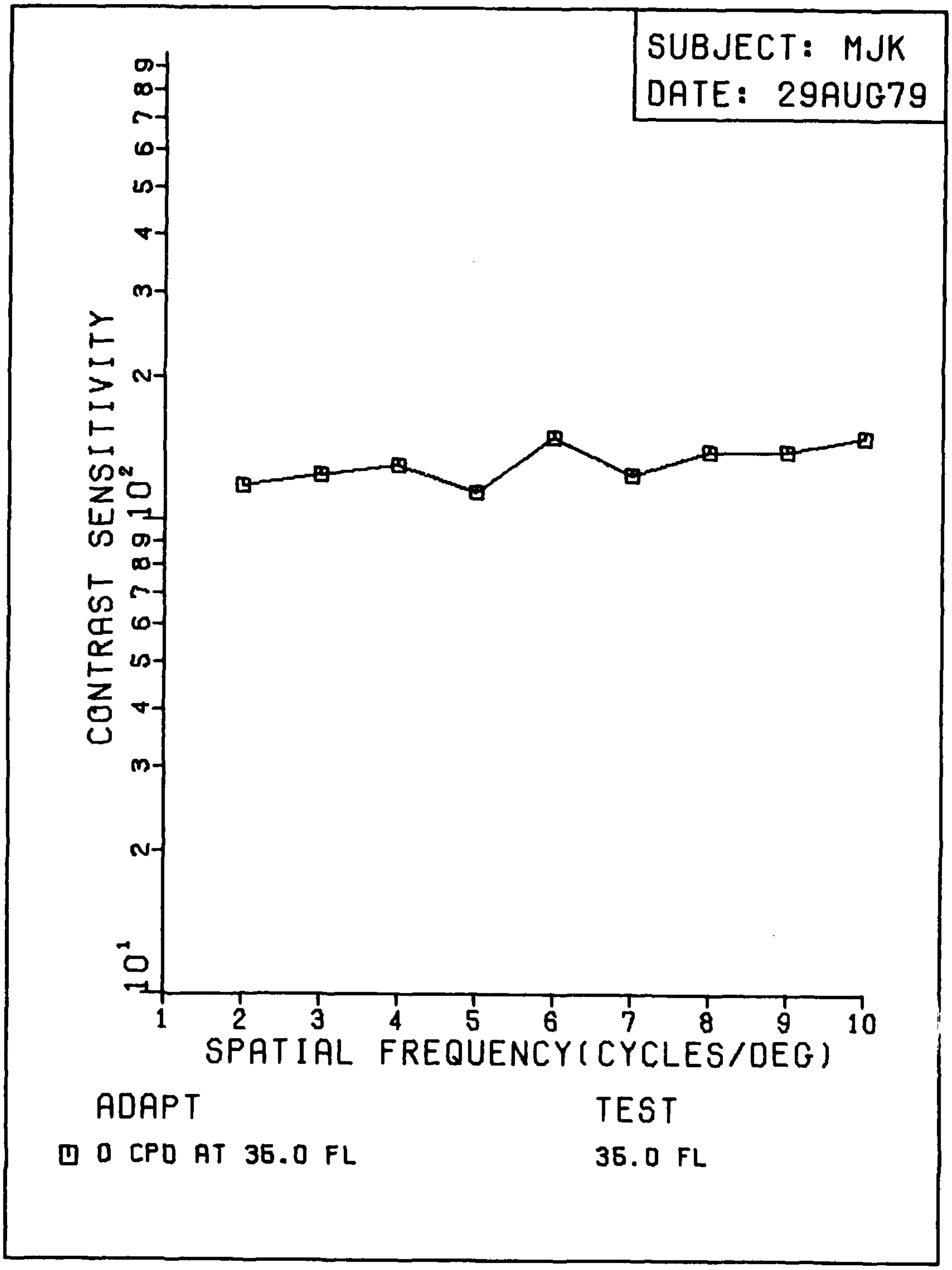


Fig. 27 MJK, 29Aug79

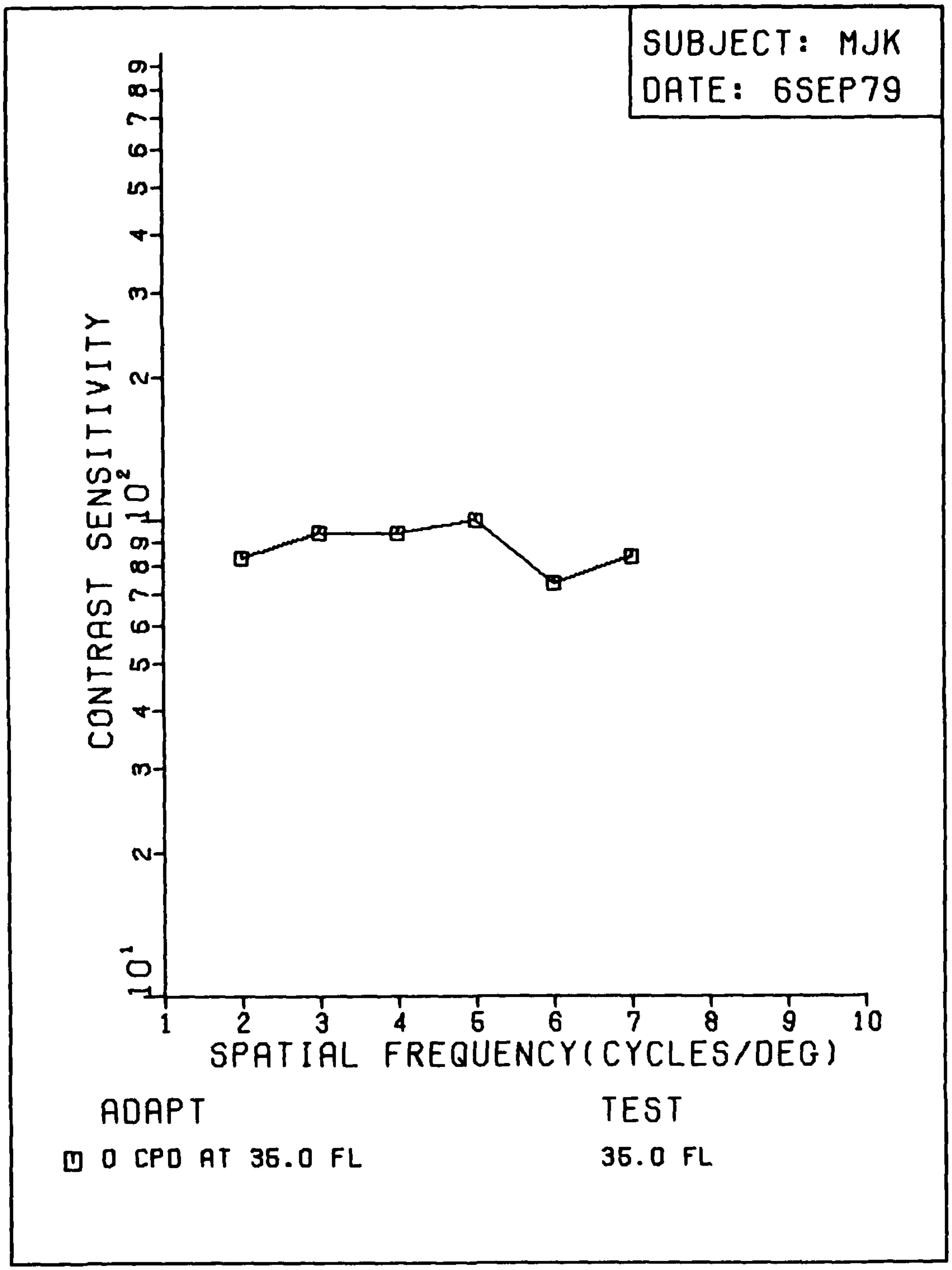


Fig. 28 MJK, 6Sep79

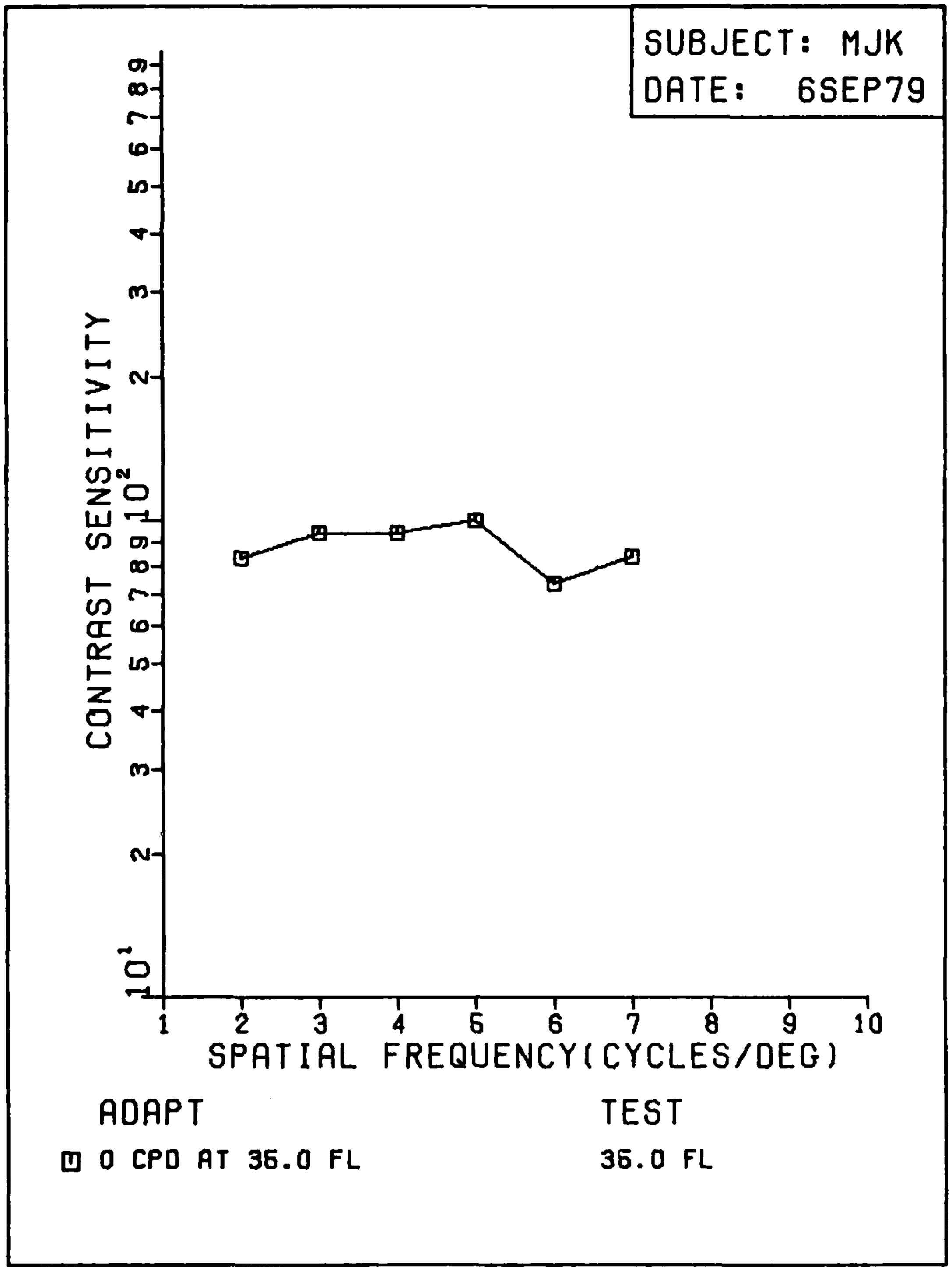


Fig. 29 MJK, 6Sep79

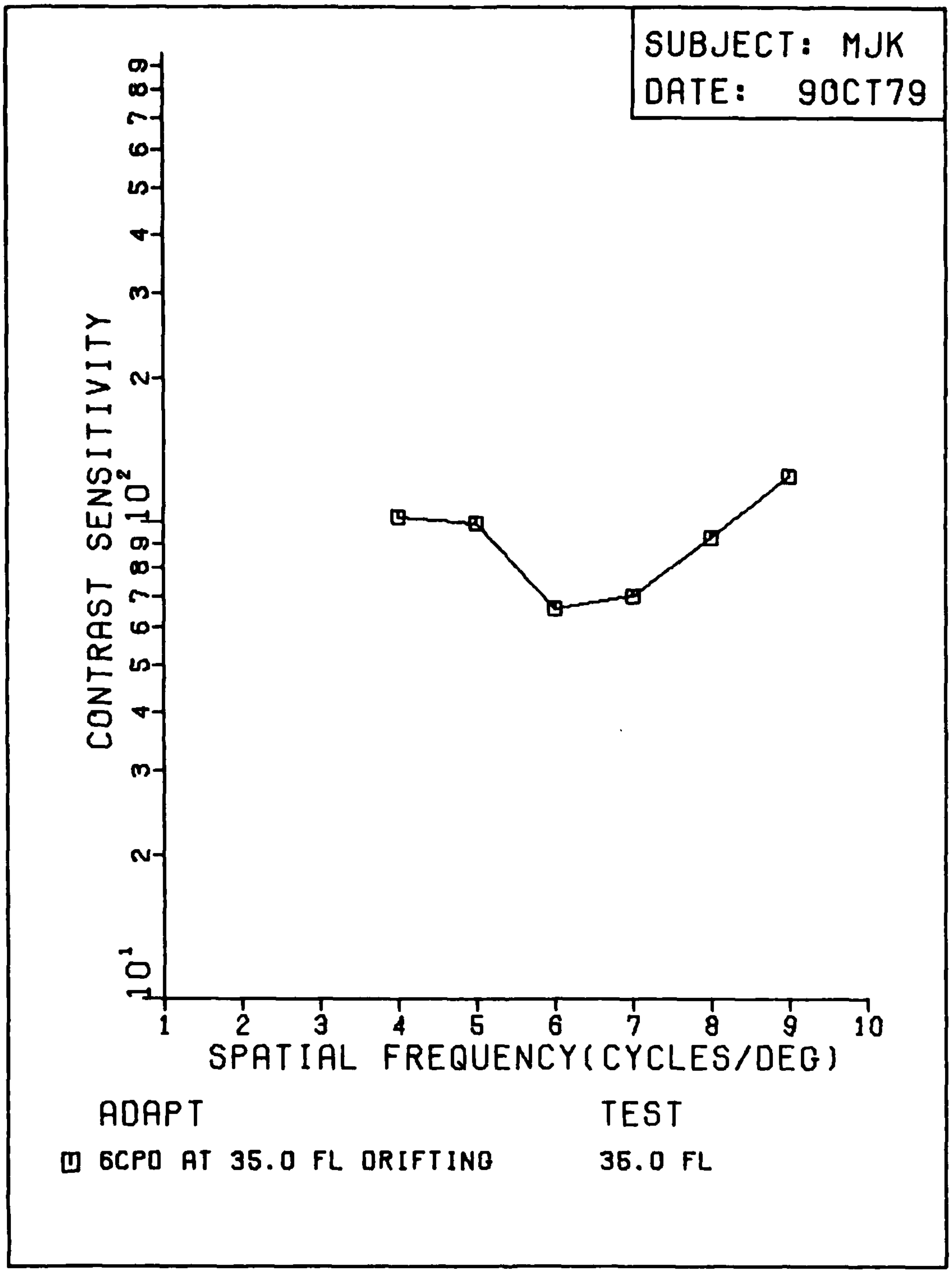


Fig. 30 MJK, 9Oct79

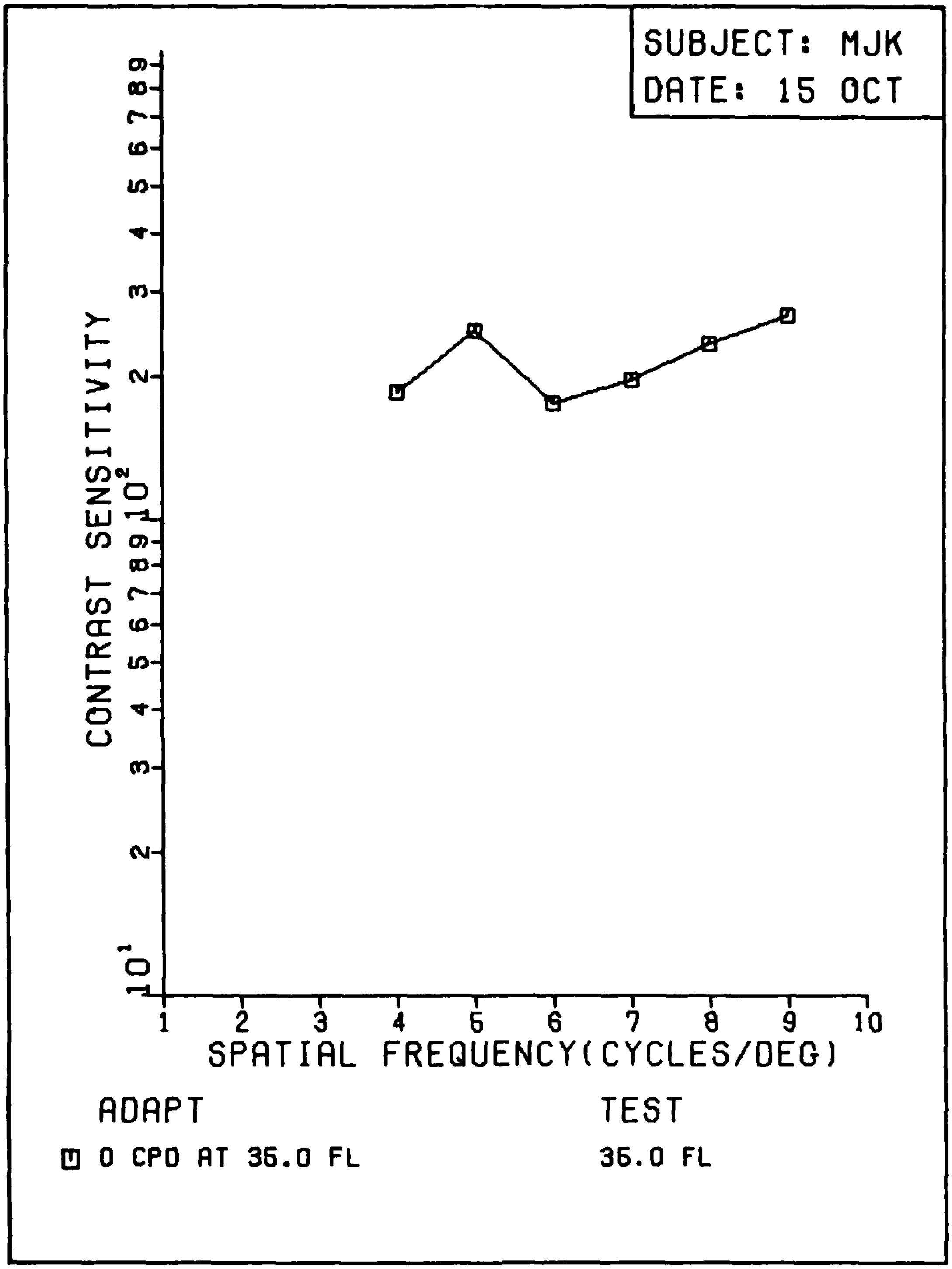


Fig. 31 MJK, 15Oct79

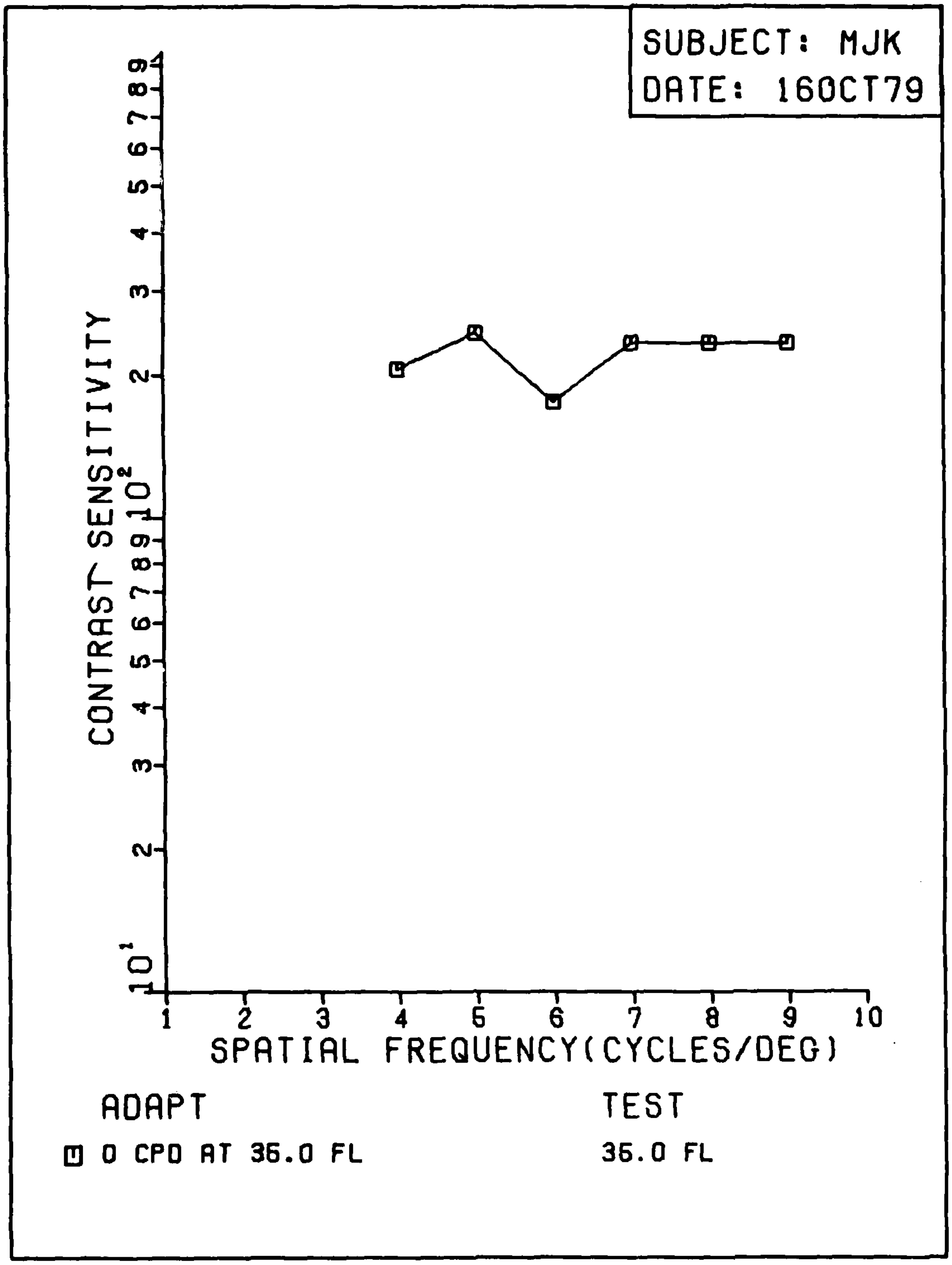


Fig. 32 MJK, 16Oct79

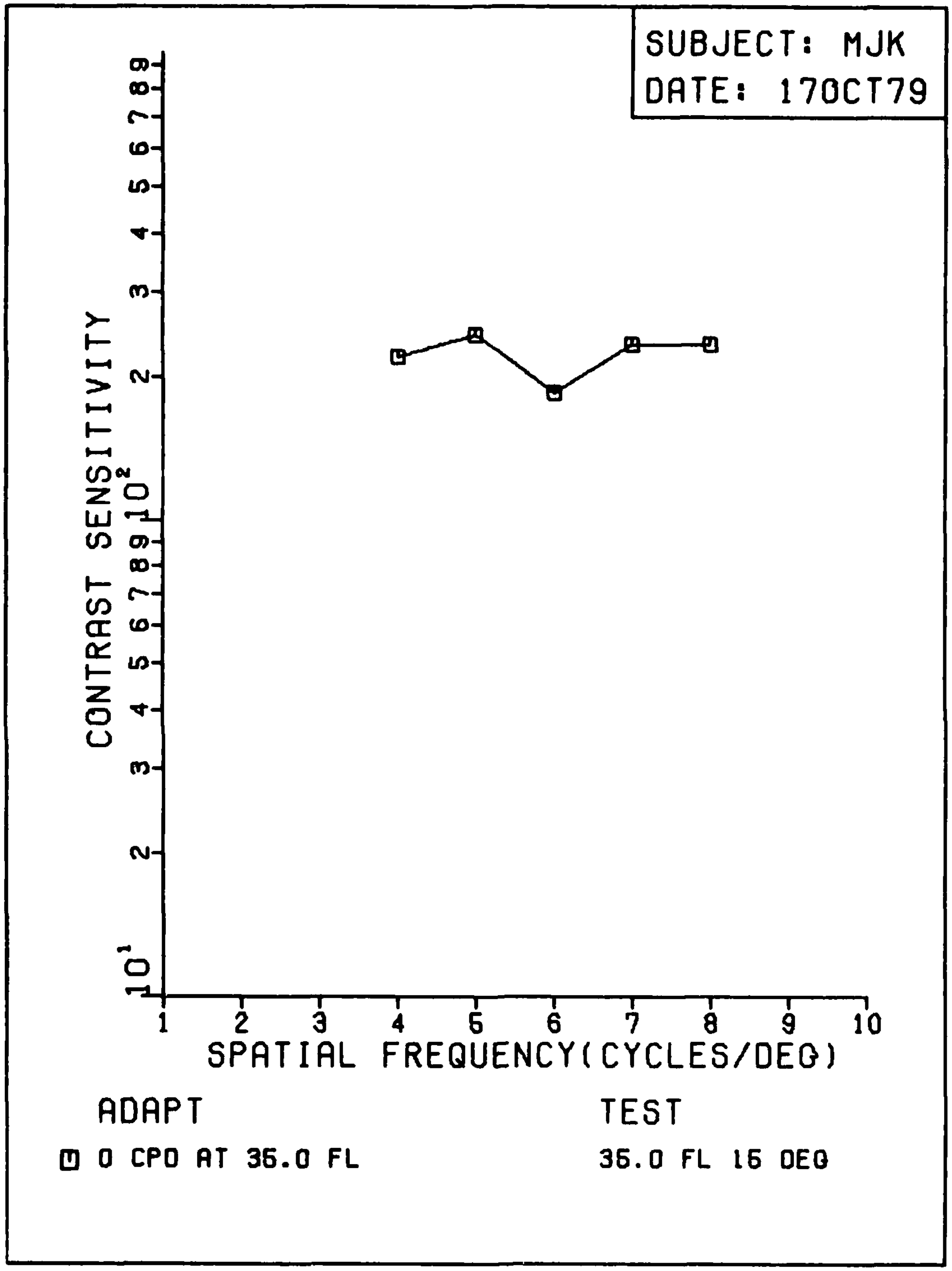


Fig. 33 MJK, 17Oct79

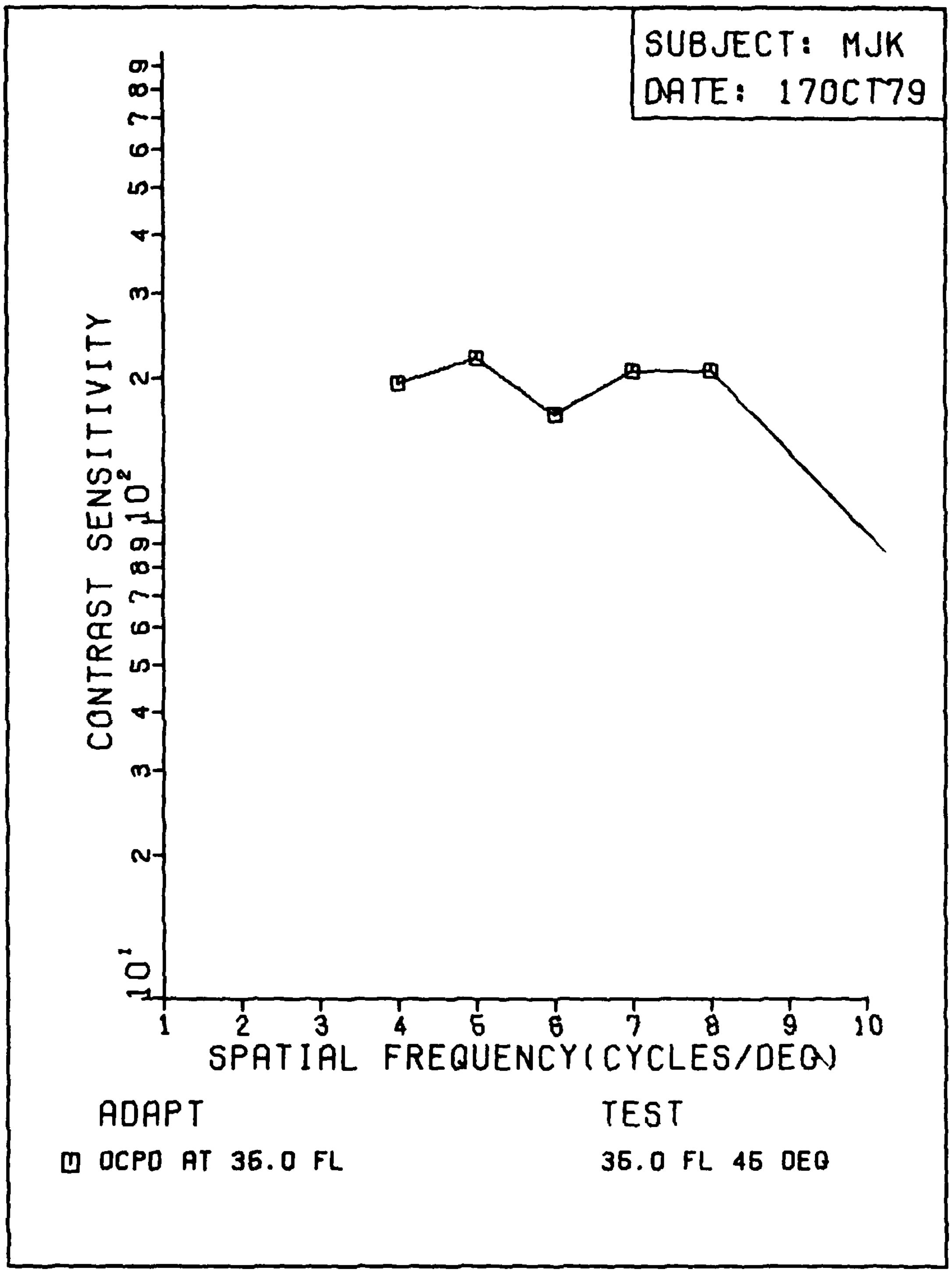


Fig. 34 MJK, 17Oct79

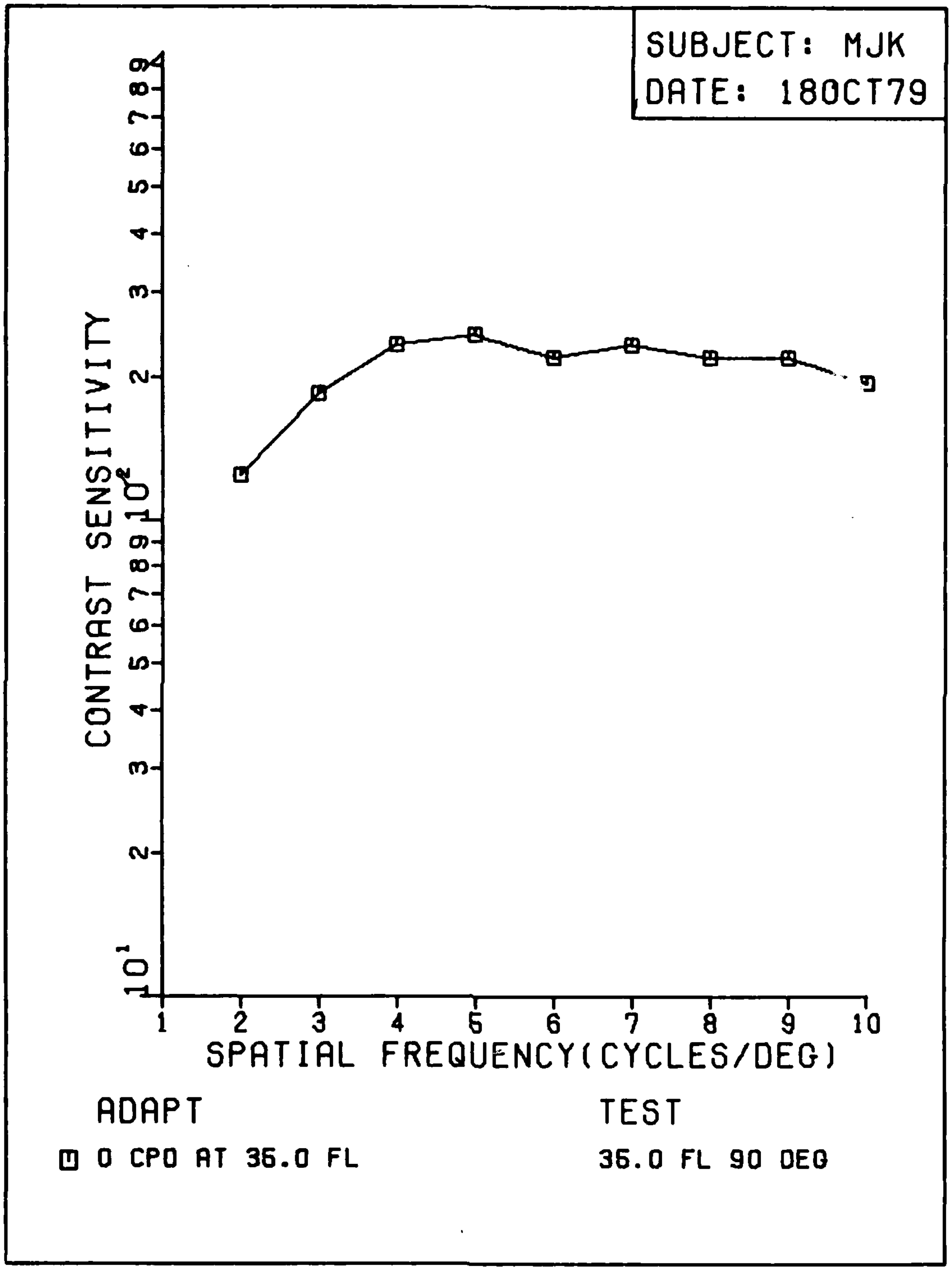


Fig. 35 MJK, 18Oct79

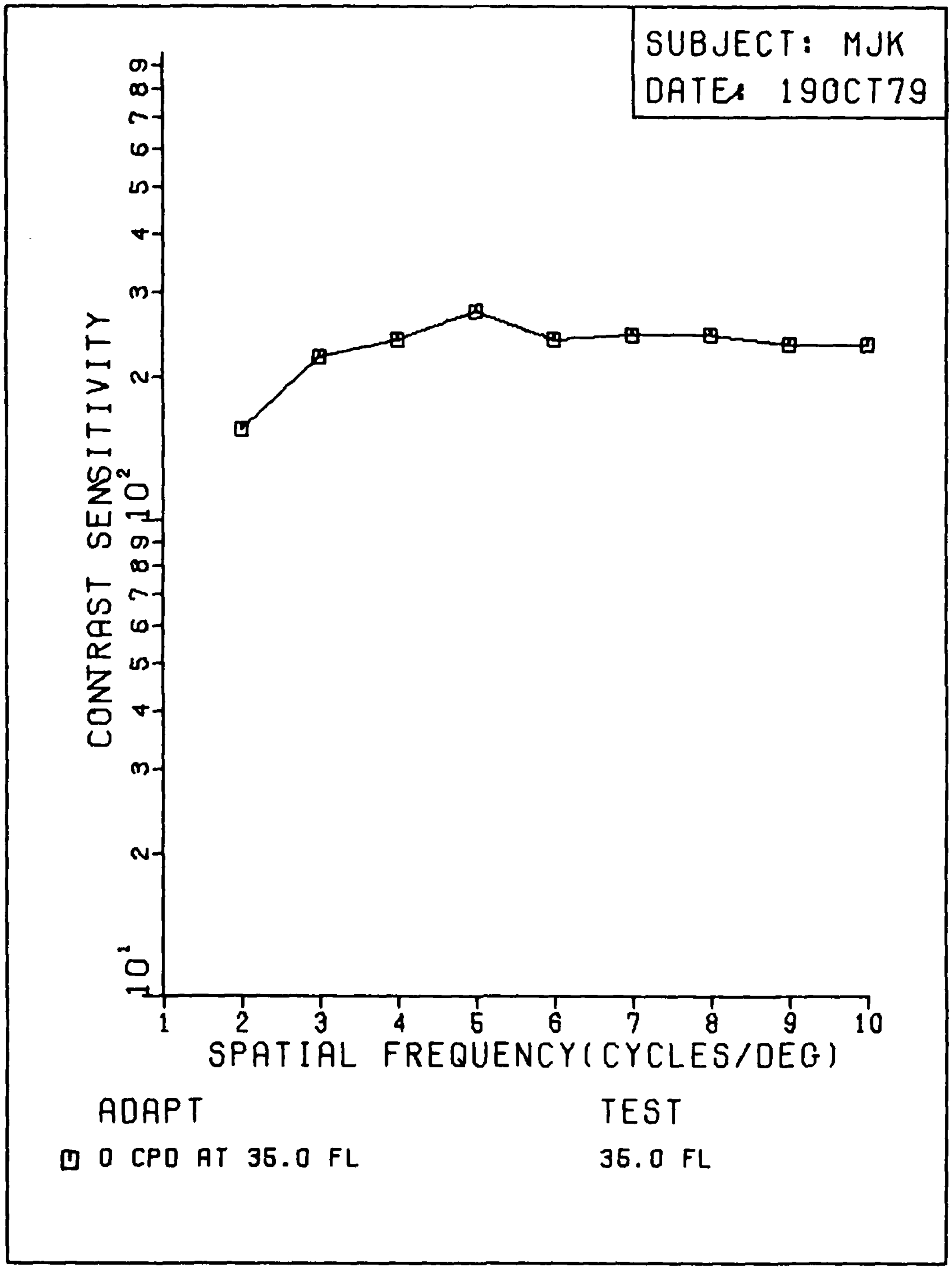


Fig. 36 MJK, 19Oct79

SUBJECT: MJK

Adapt: Dim

Test: Dim

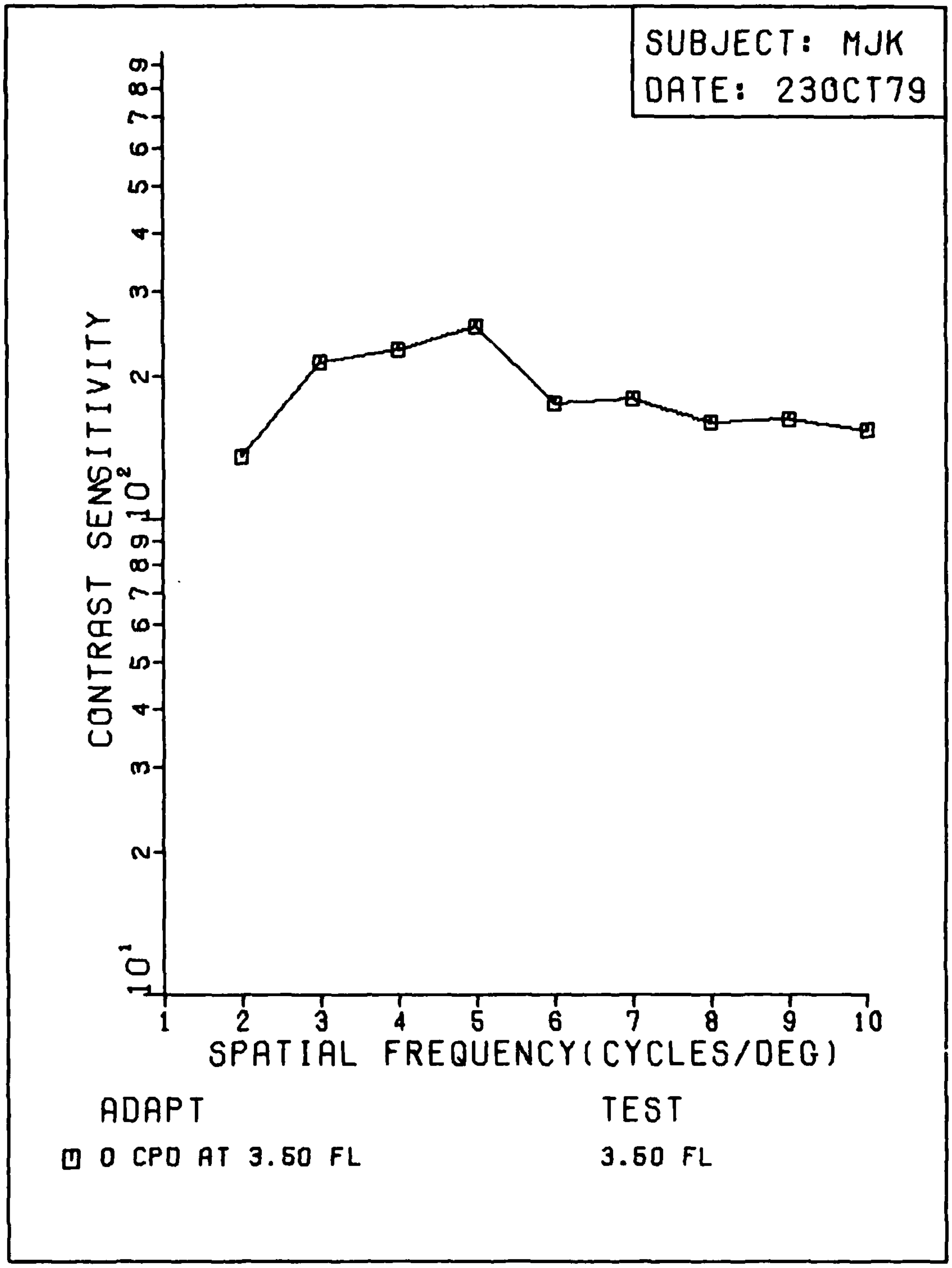


Fig. 37 MJK, 23Oct79

SUBJECT: MJK

Adapt: Bright

Test: Dim

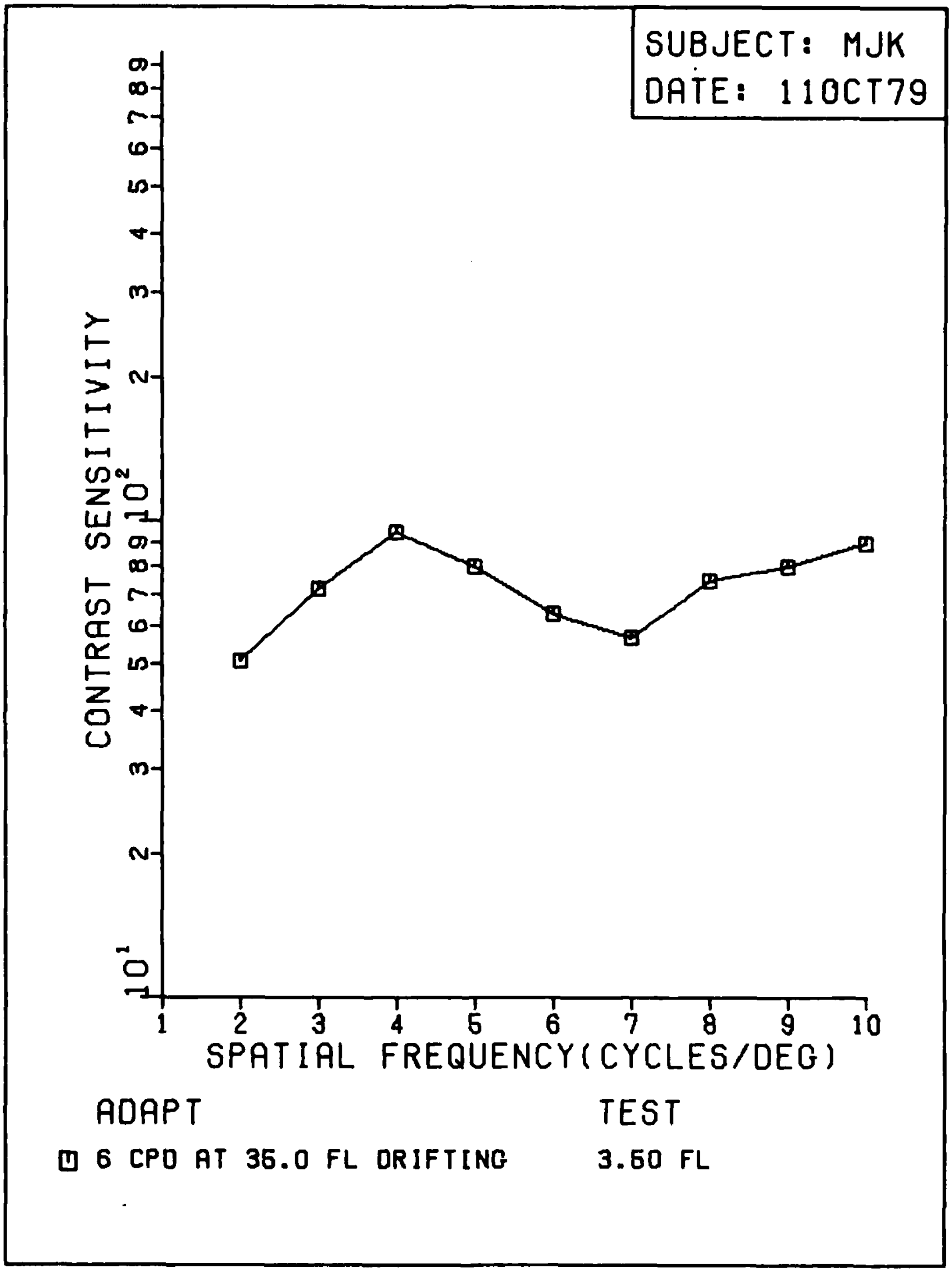


Fig. 38 MJK, 11Oct79

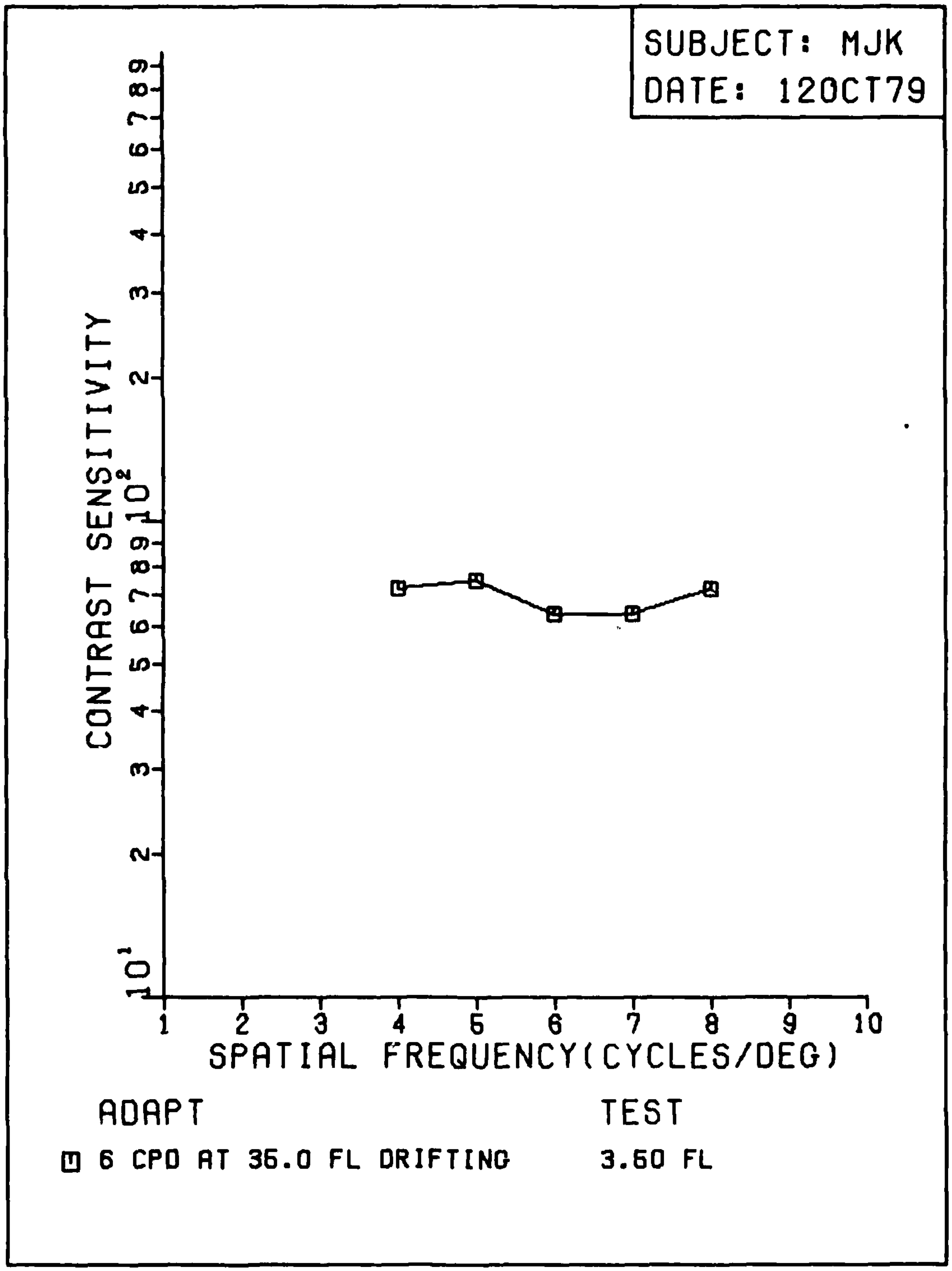


Fig. 39 MJK, 12Oct79

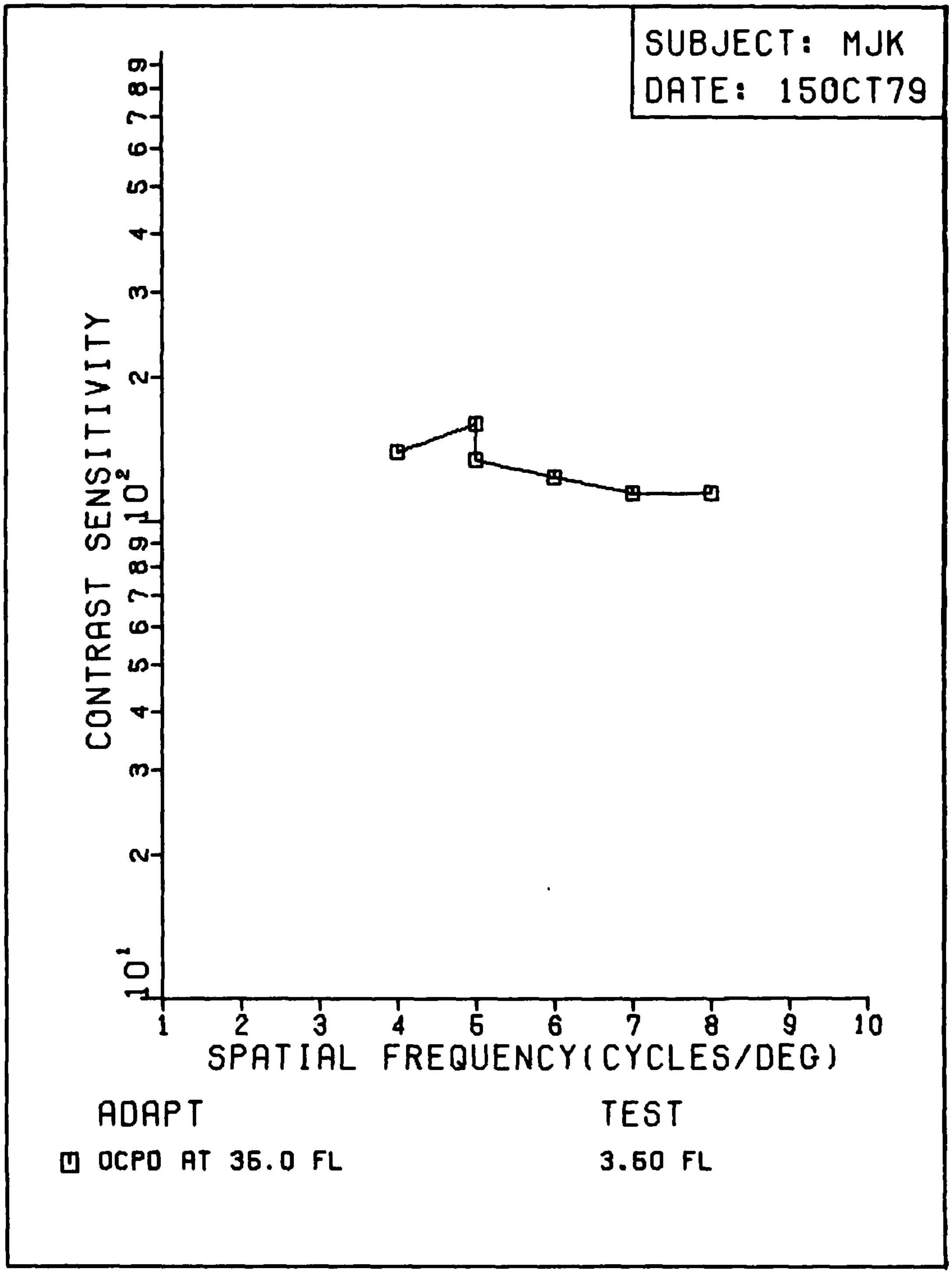


Fig. 40 MJK, 15Oct79

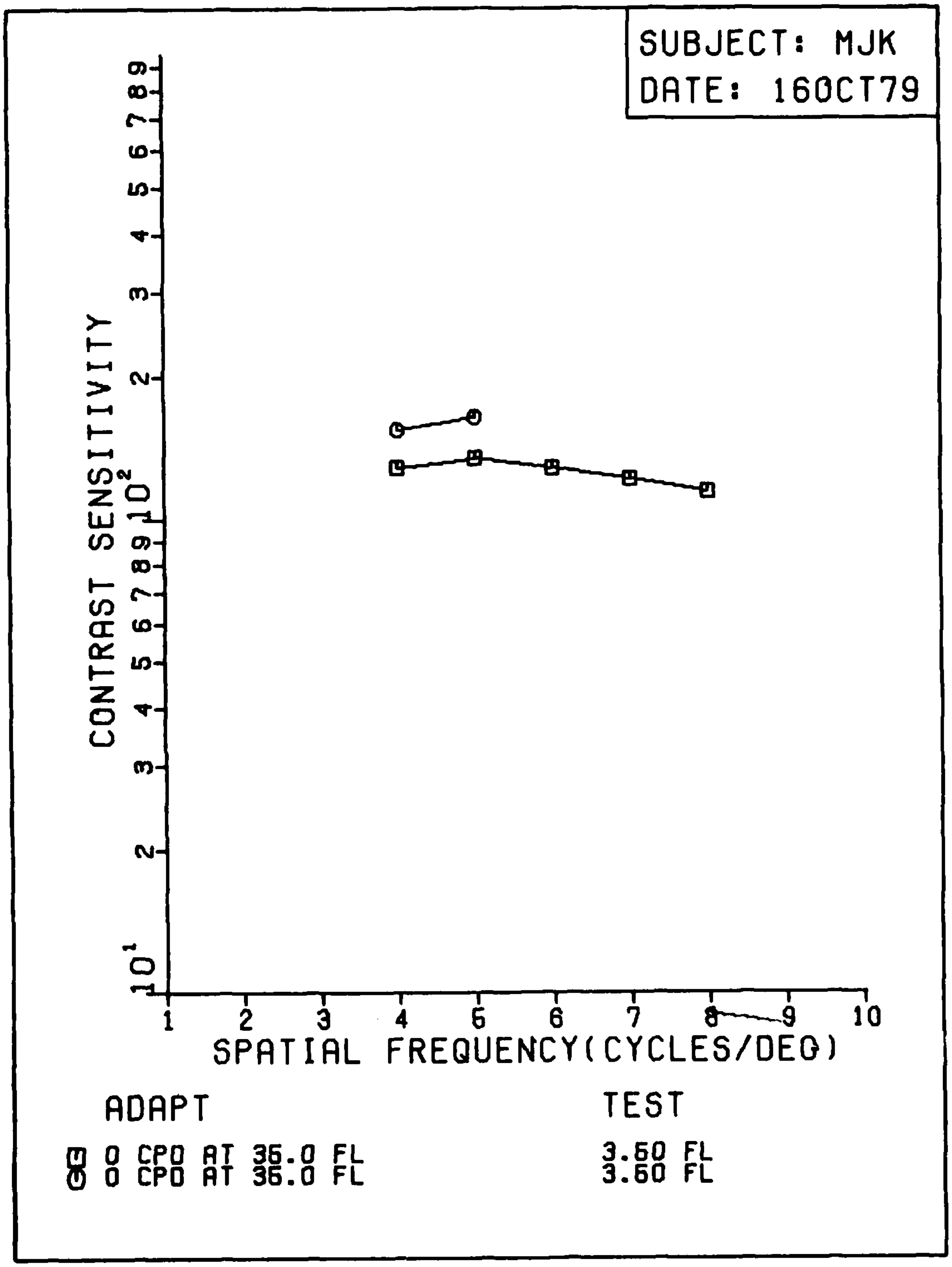


Fig. 41 MJK, 16Oct79

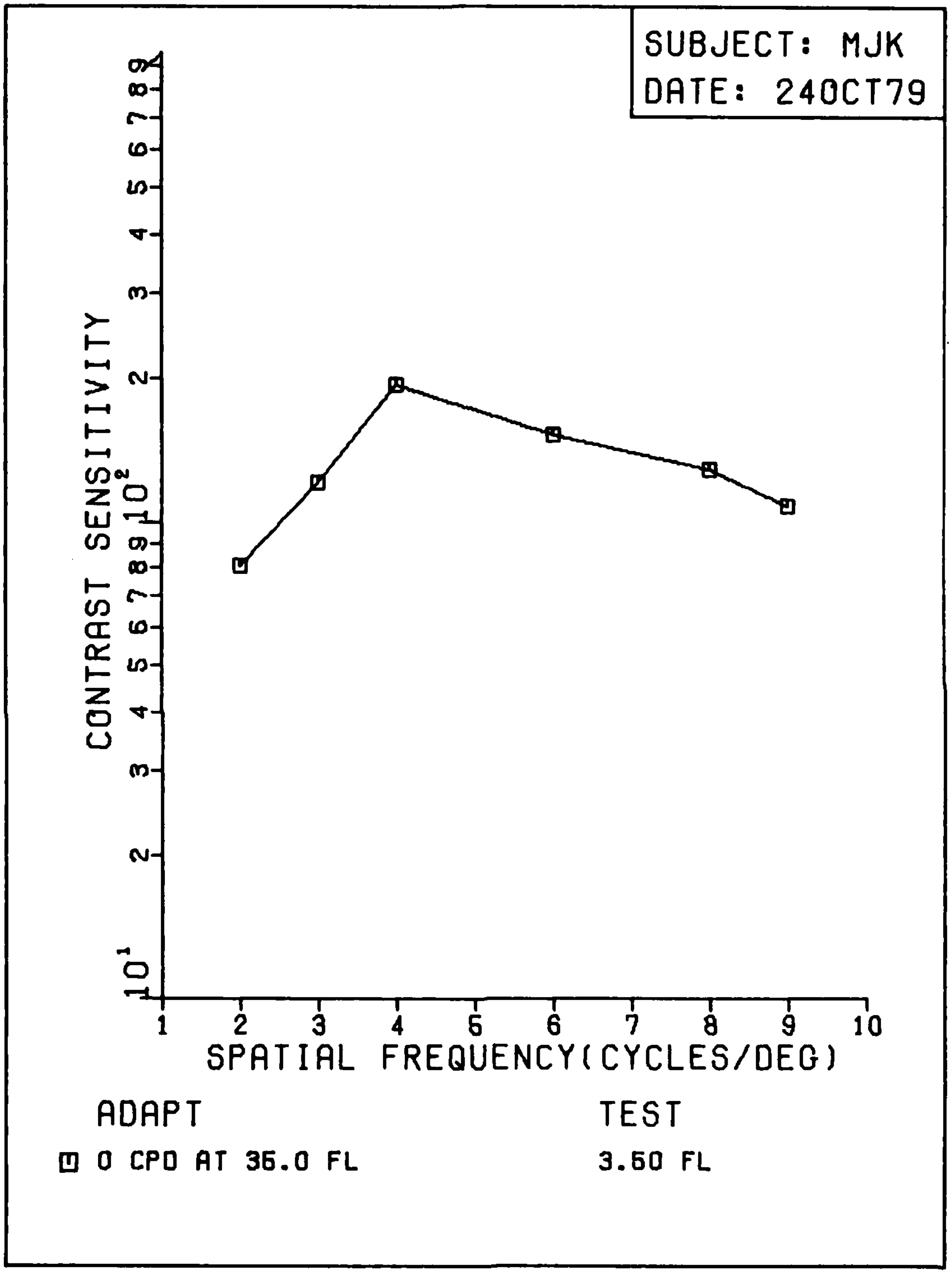


Fig. 42 MJK, 24Oct79

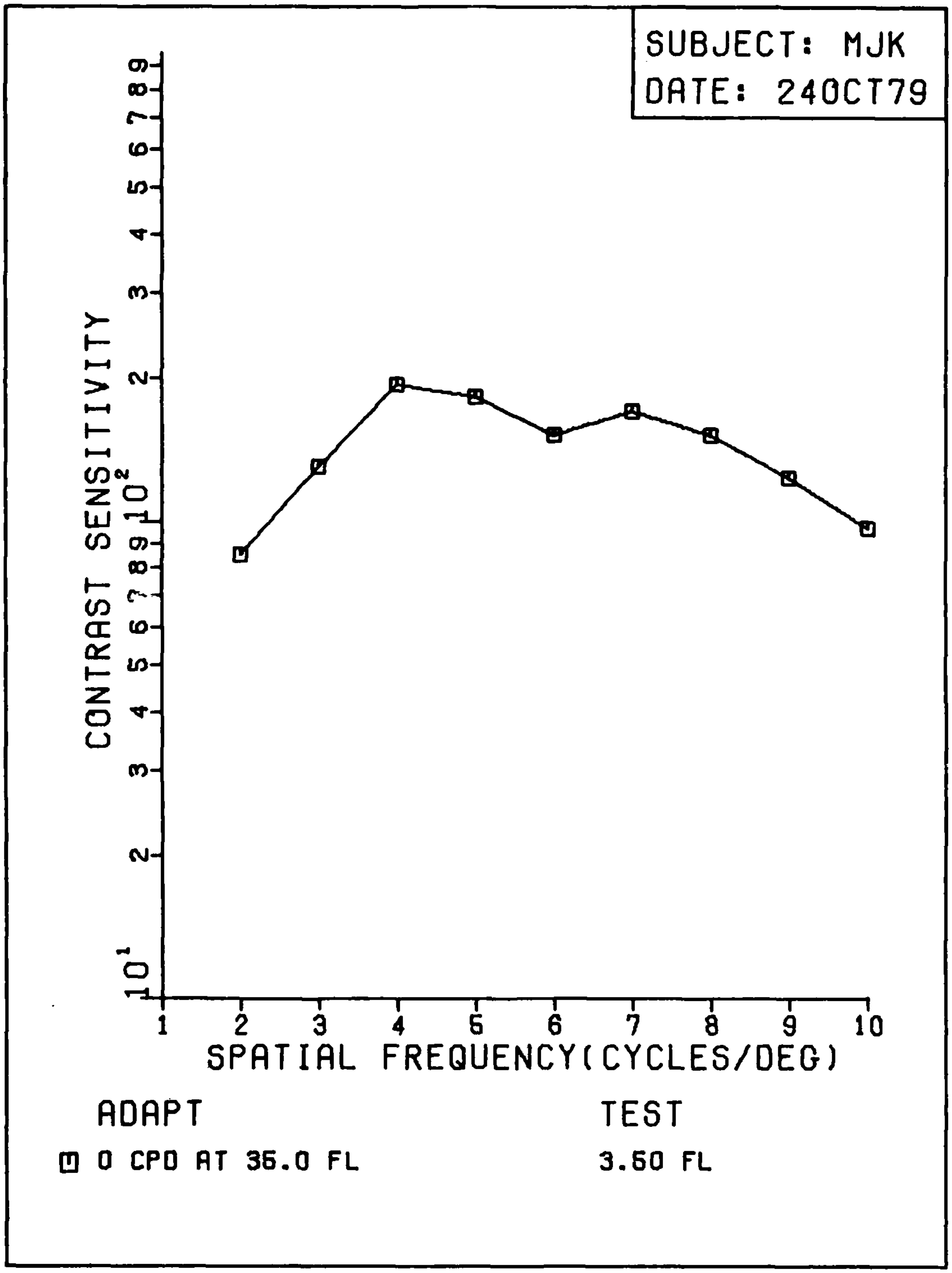


Fig. 43 MJK, 24Oct79

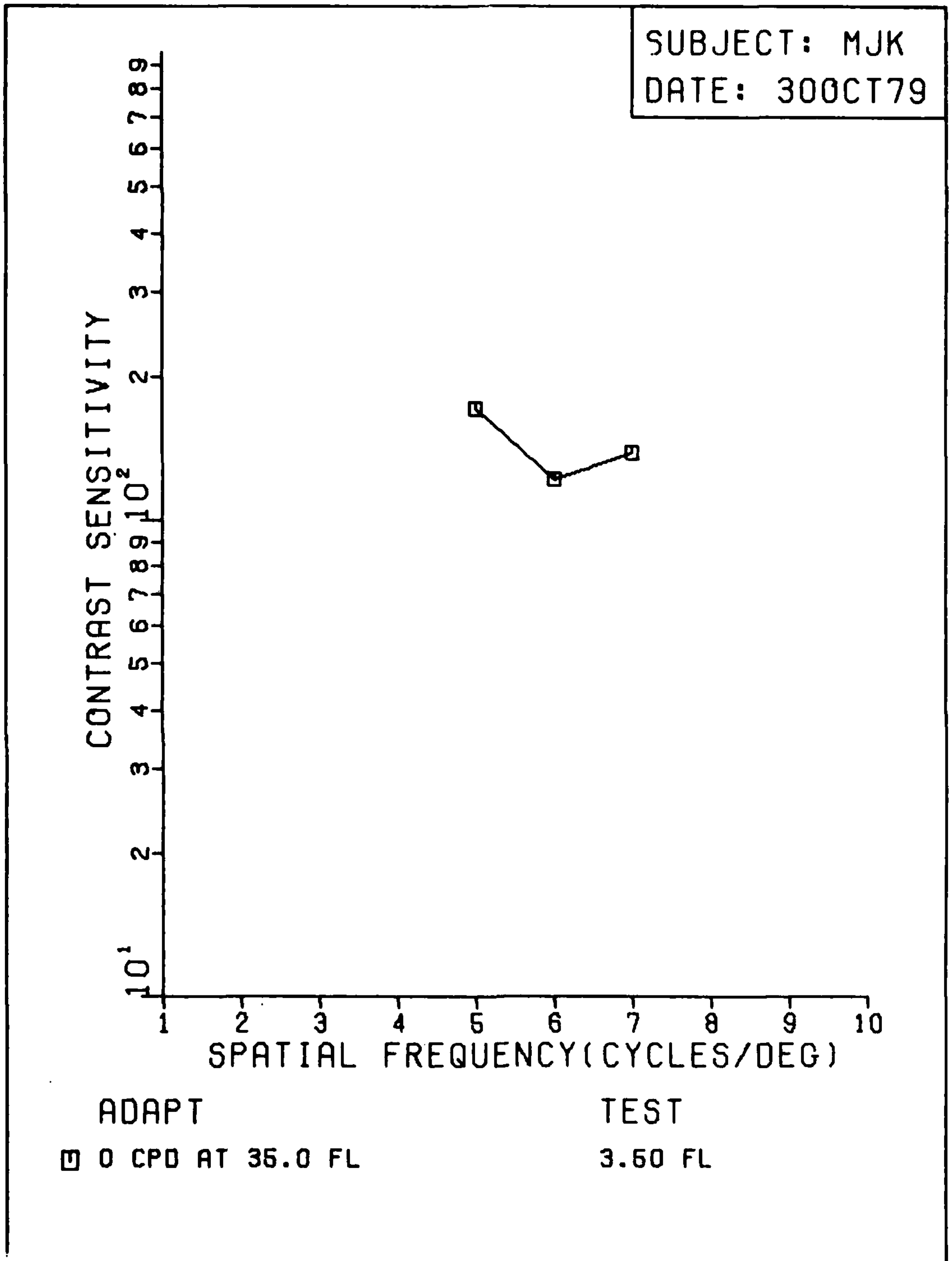


Fig. 44 MJK, 30Oct79

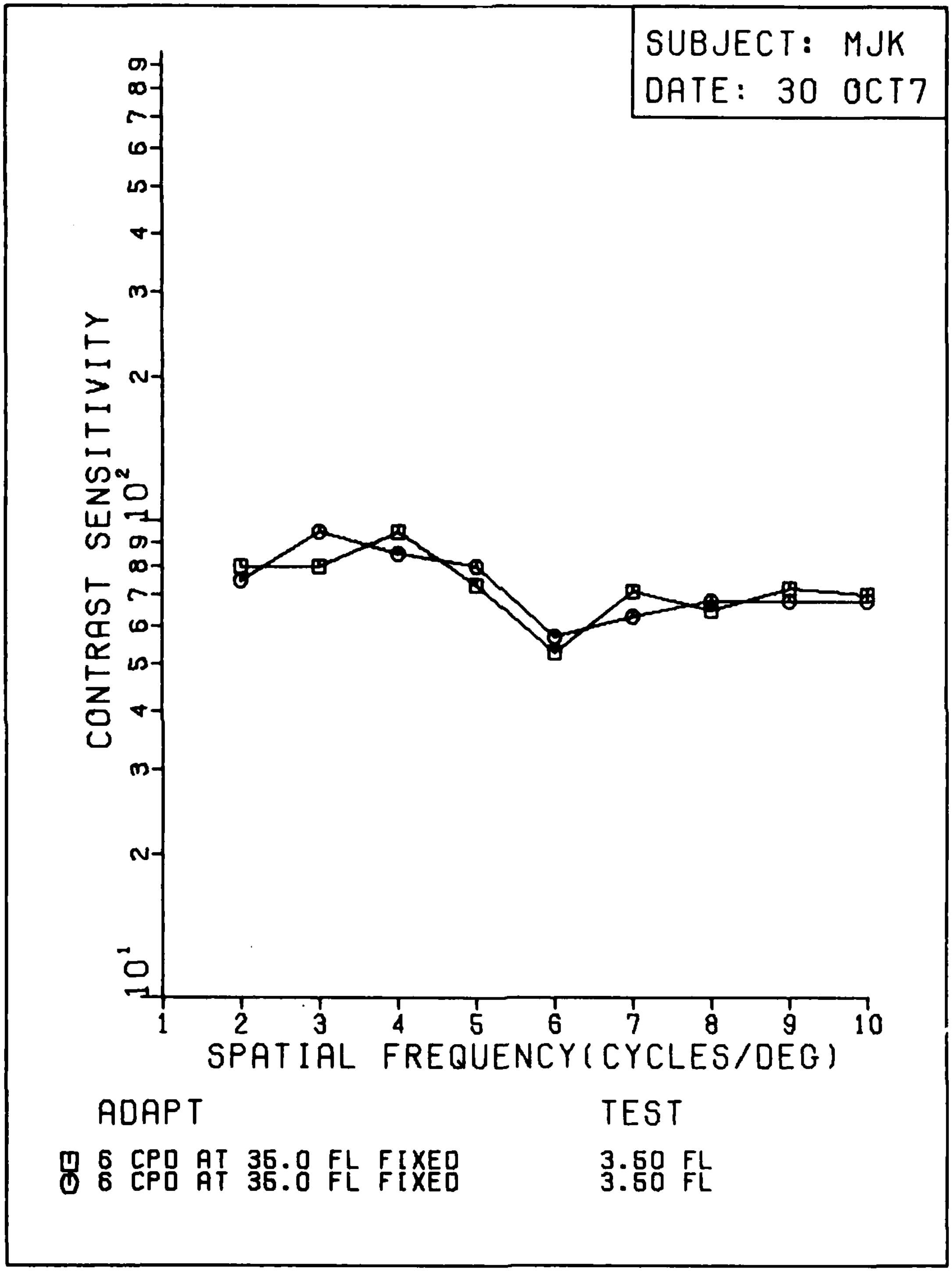


Fig. 45 MJK, 30Oct79

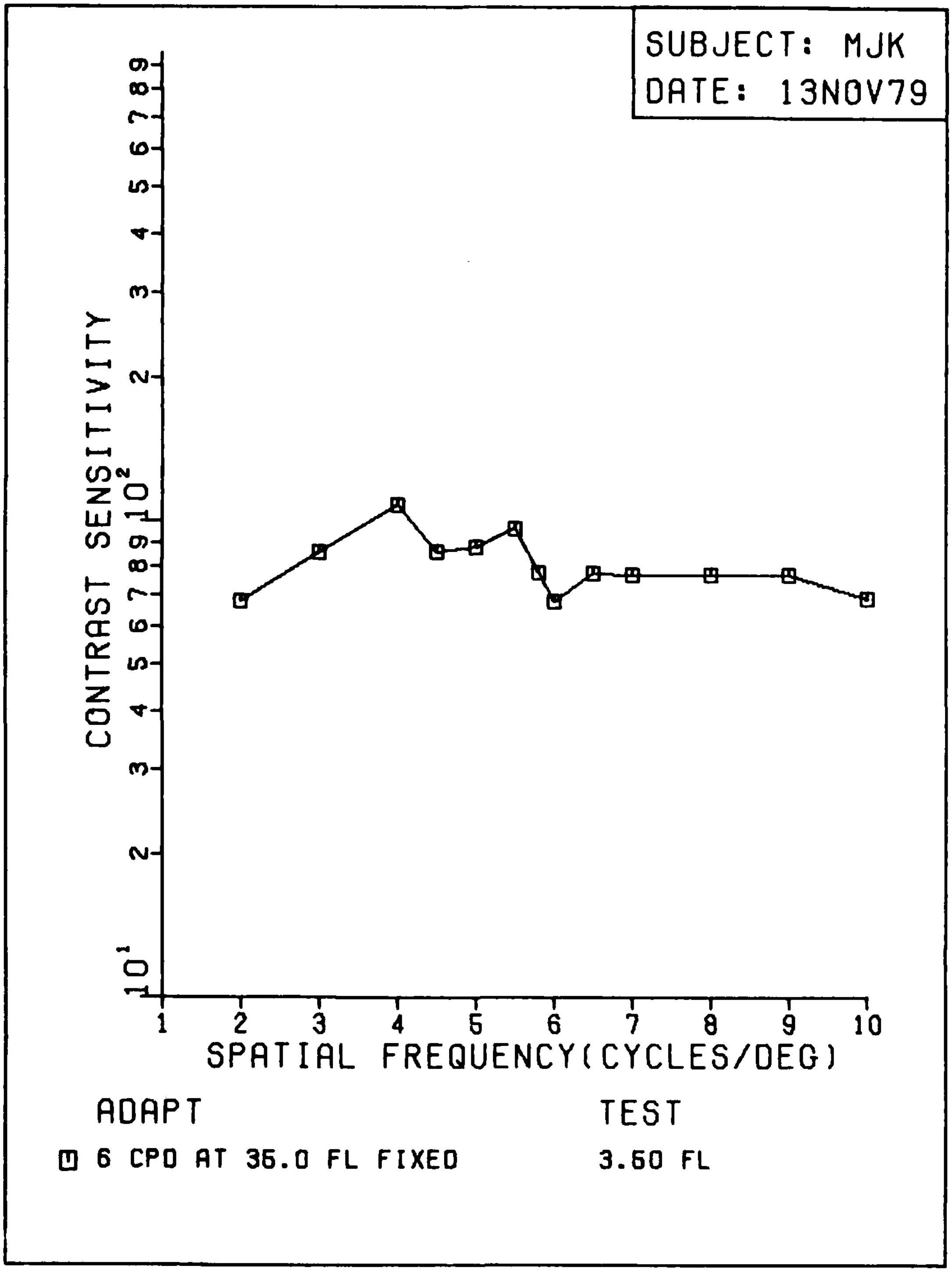


Fig. 46 MJK, 13Nov79

SUBJECT: MJK

Adapt: Dim

Test: Bright

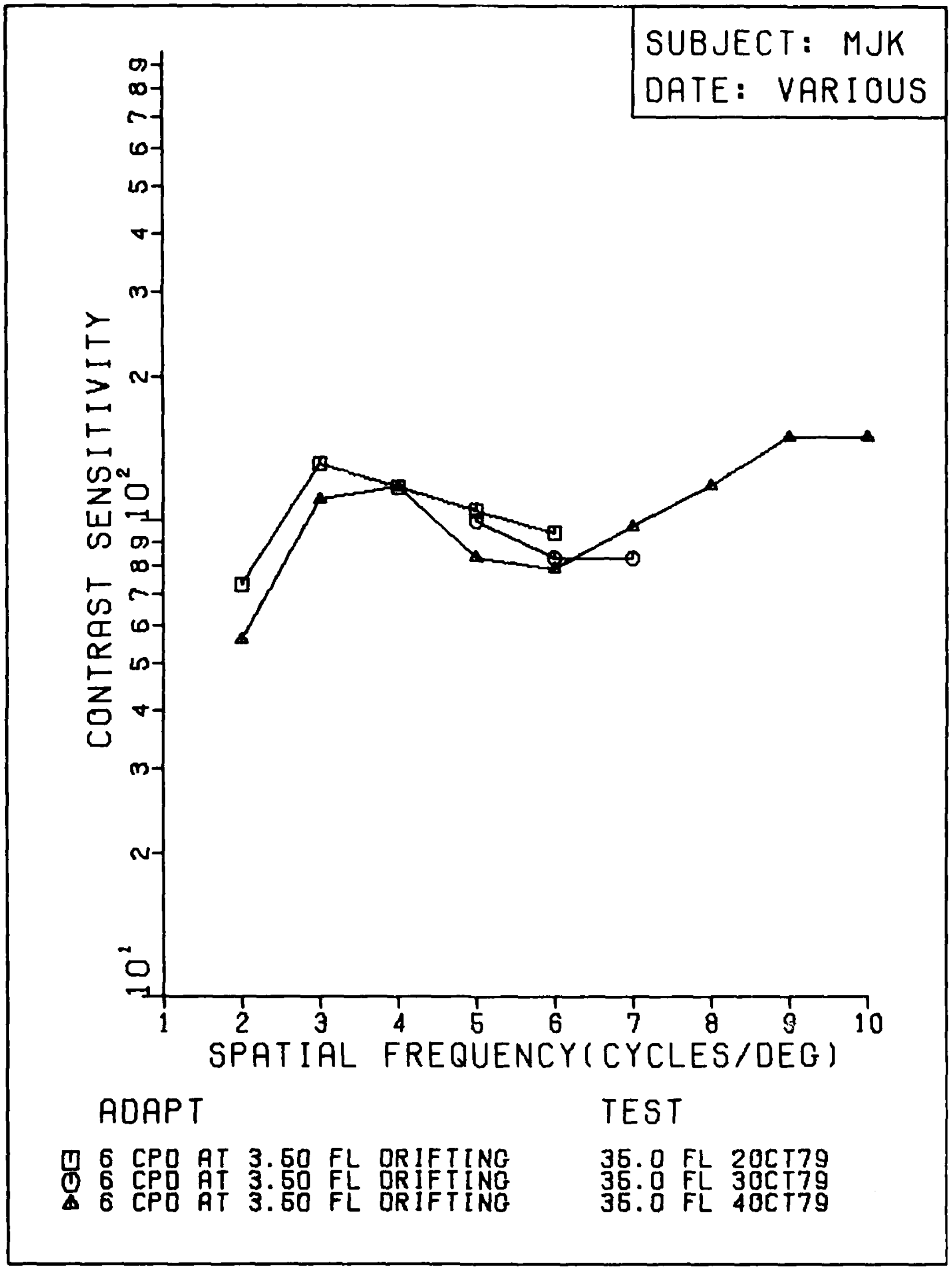


Fig. 47 MJK, Various

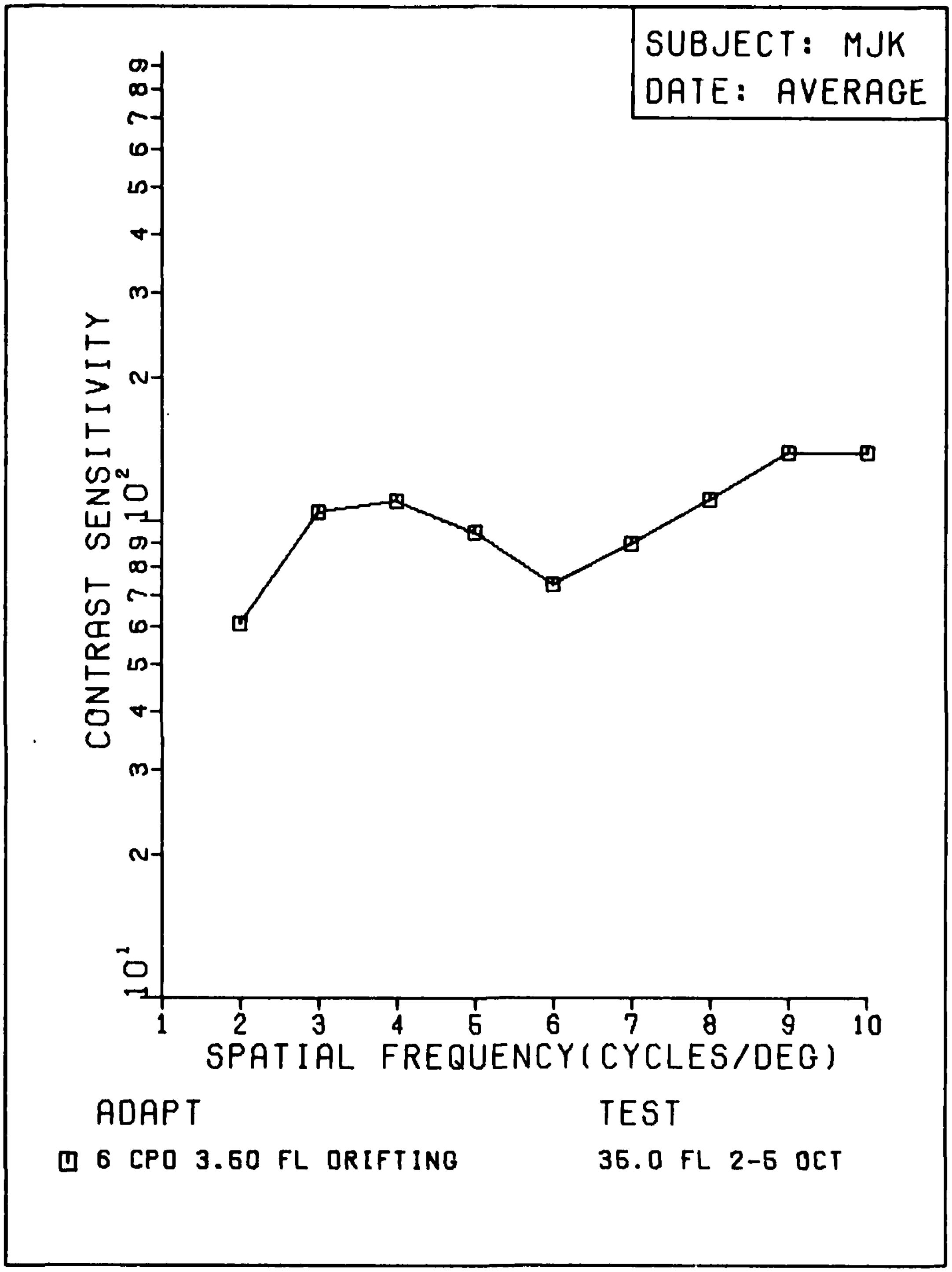


Fig. 48 MJK, Average

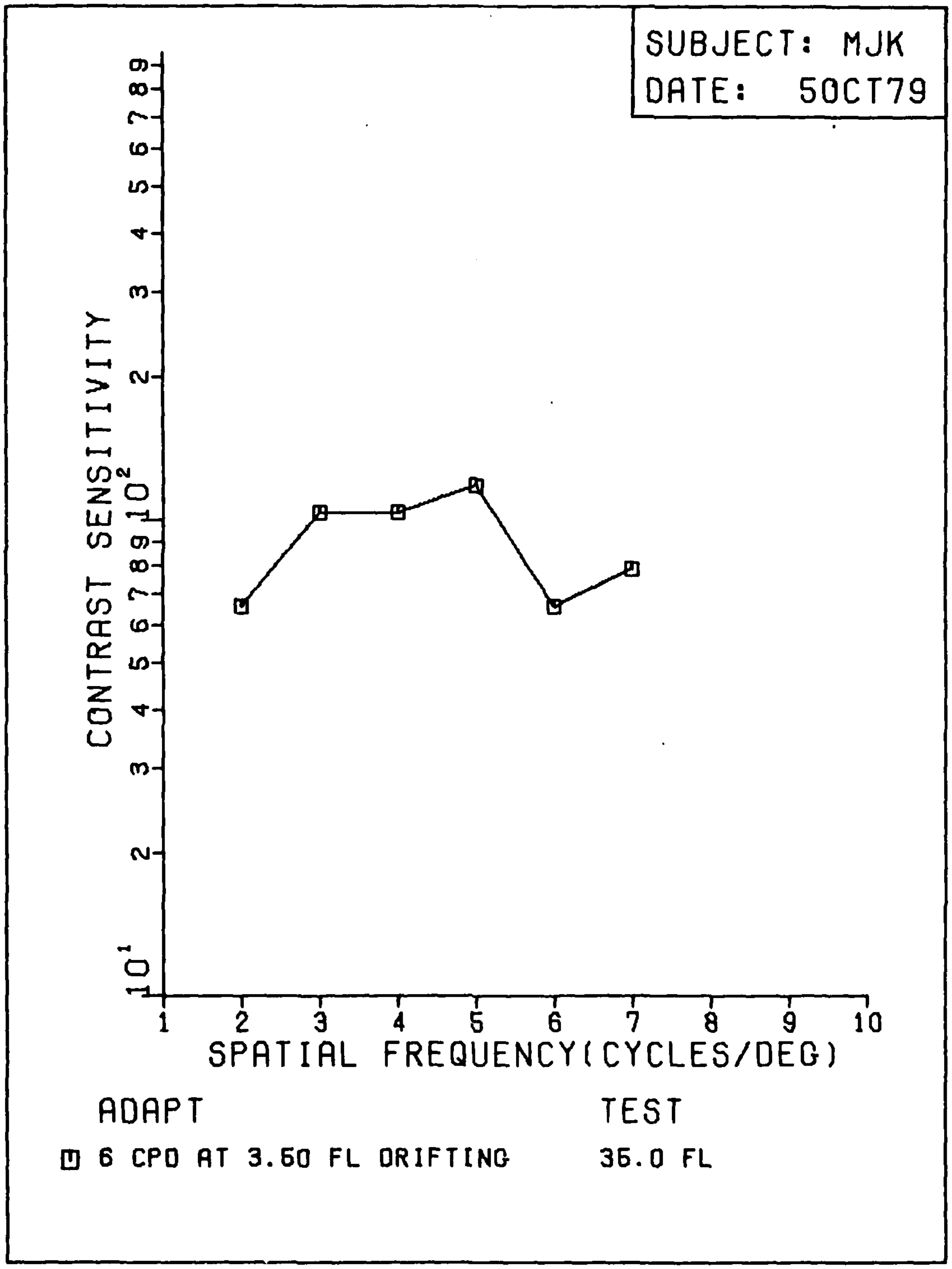


Fig. 49 MJK, 5Oct79

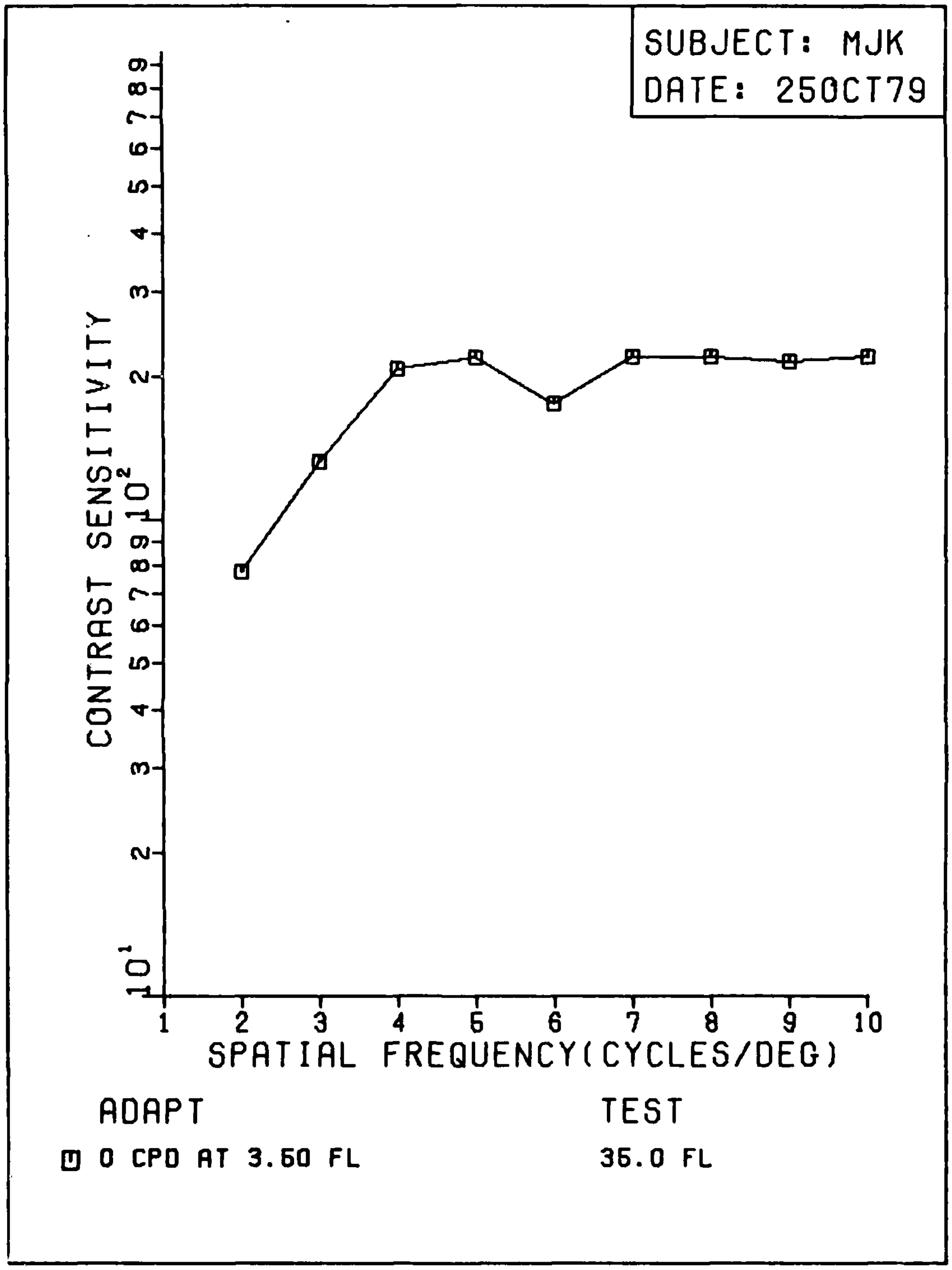


Fig. 50 MJK,25Oct79

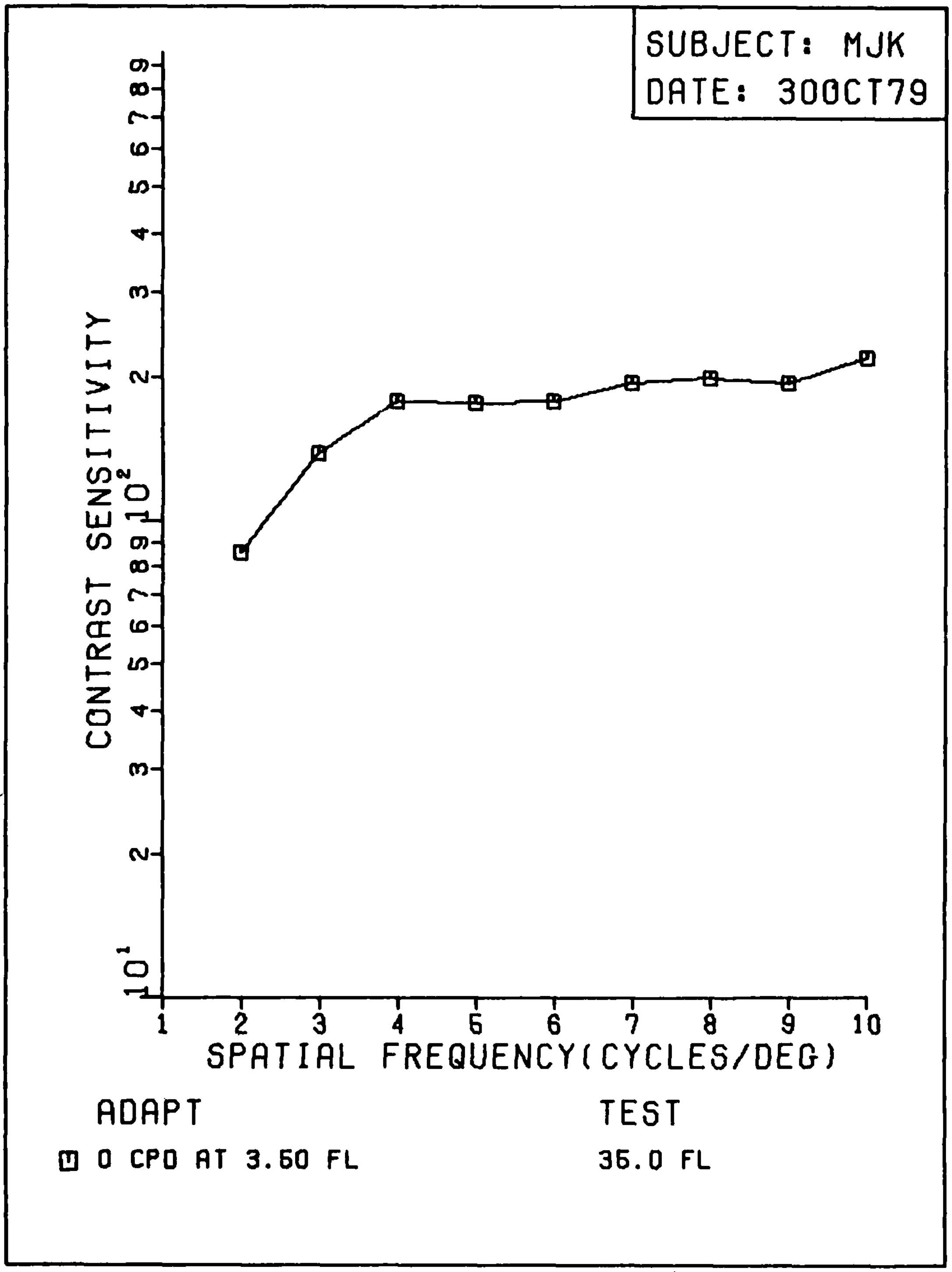


Fig. 51 MJK, 30Oct79

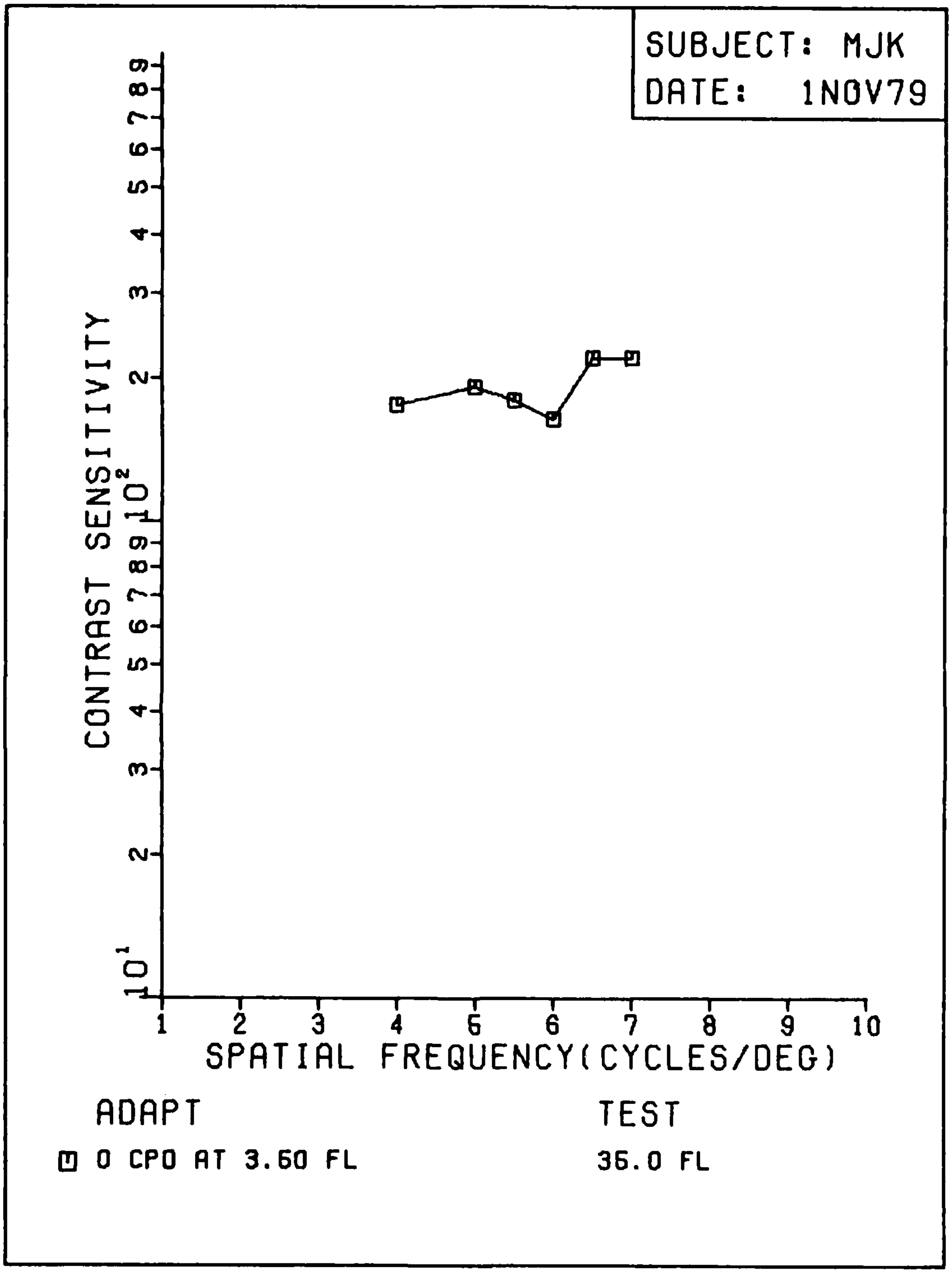


Fig. 52 MJK, 1Nov79

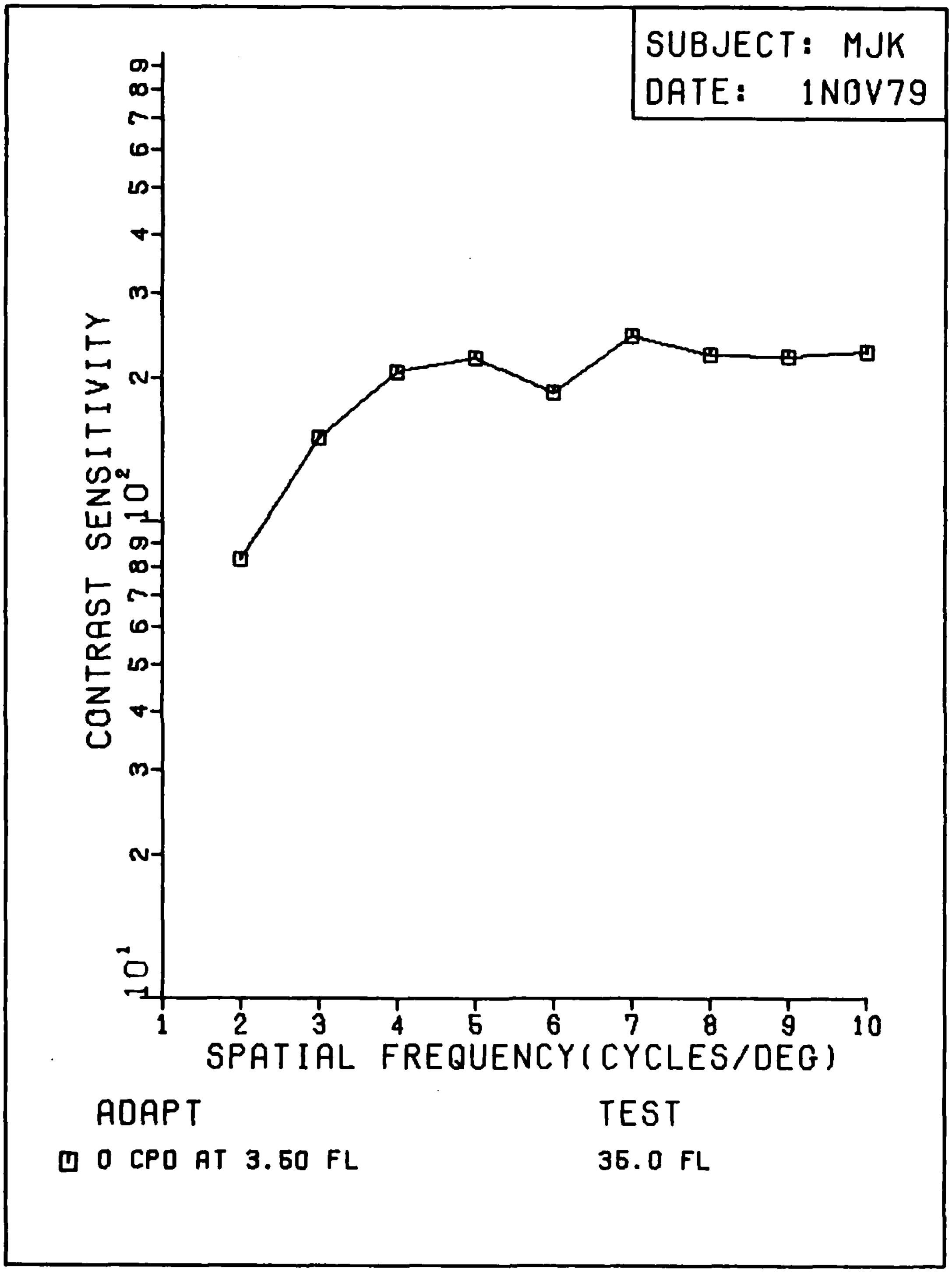


Fig. 53 MJK, 1Nov79

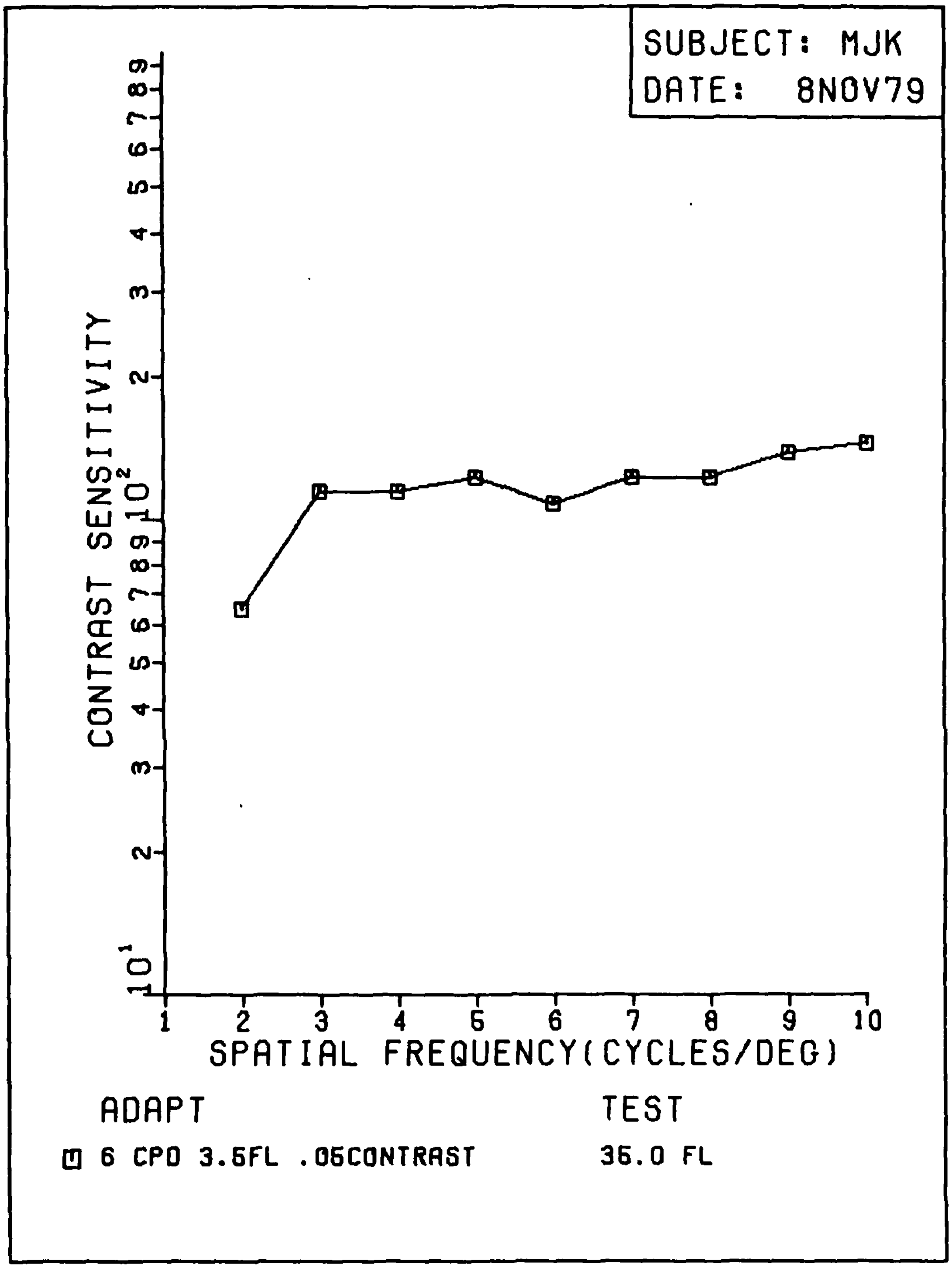


Fig. 54 MJK, 8Nov79

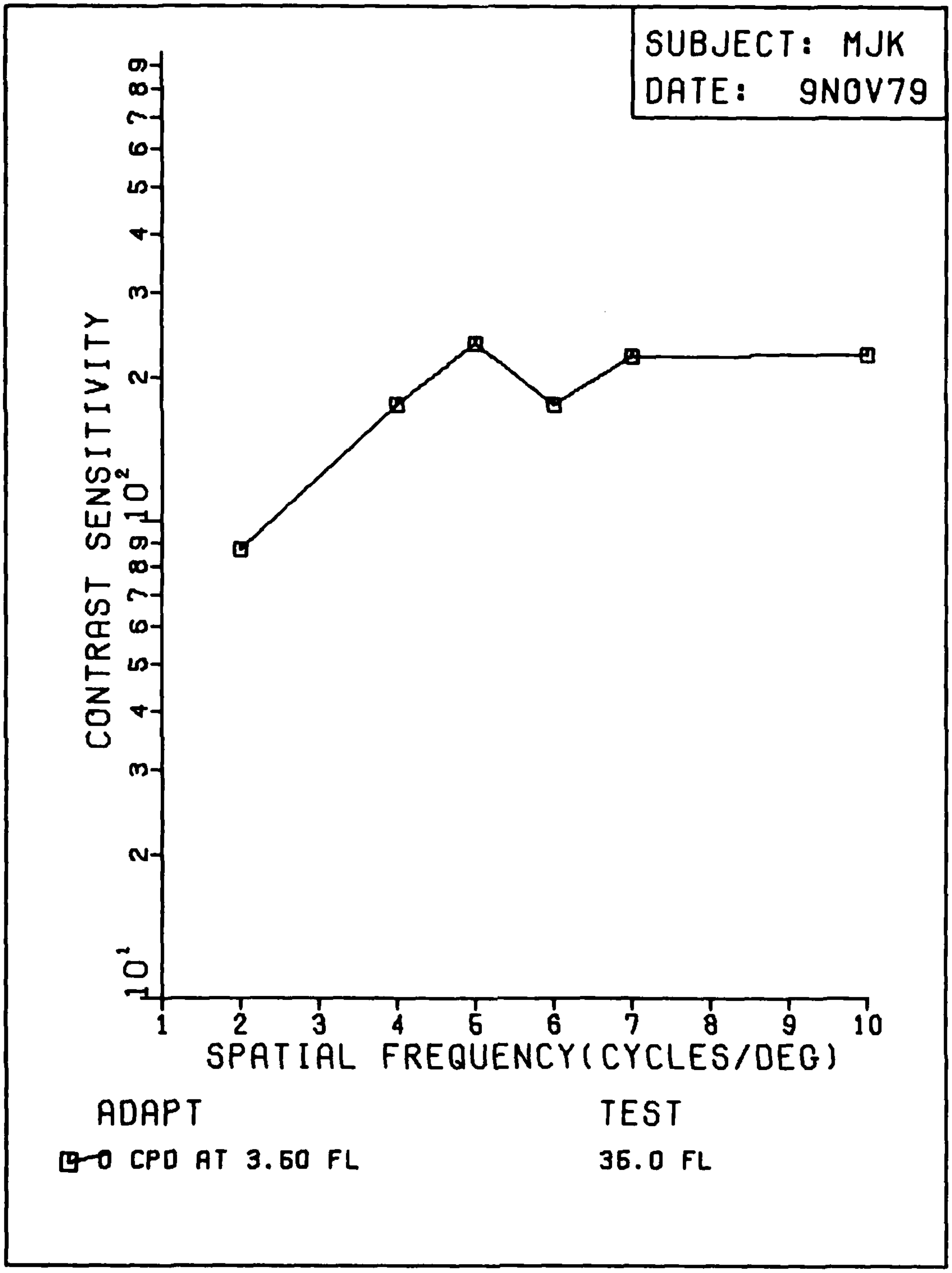


Fig. 55 MJK, 9Nov79

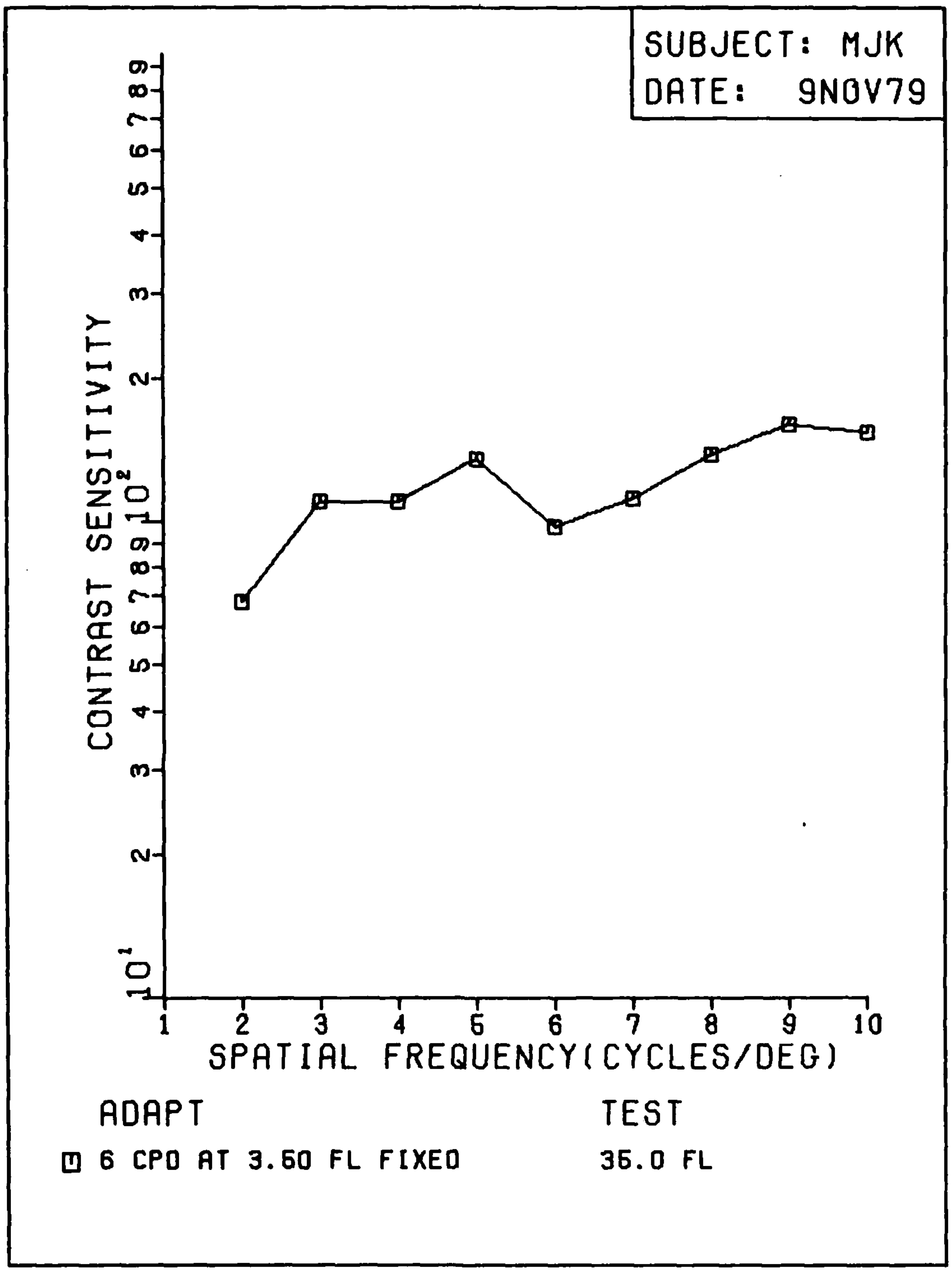


Fig. 56 MJK, 9Nov79

SUBJECT: SDP

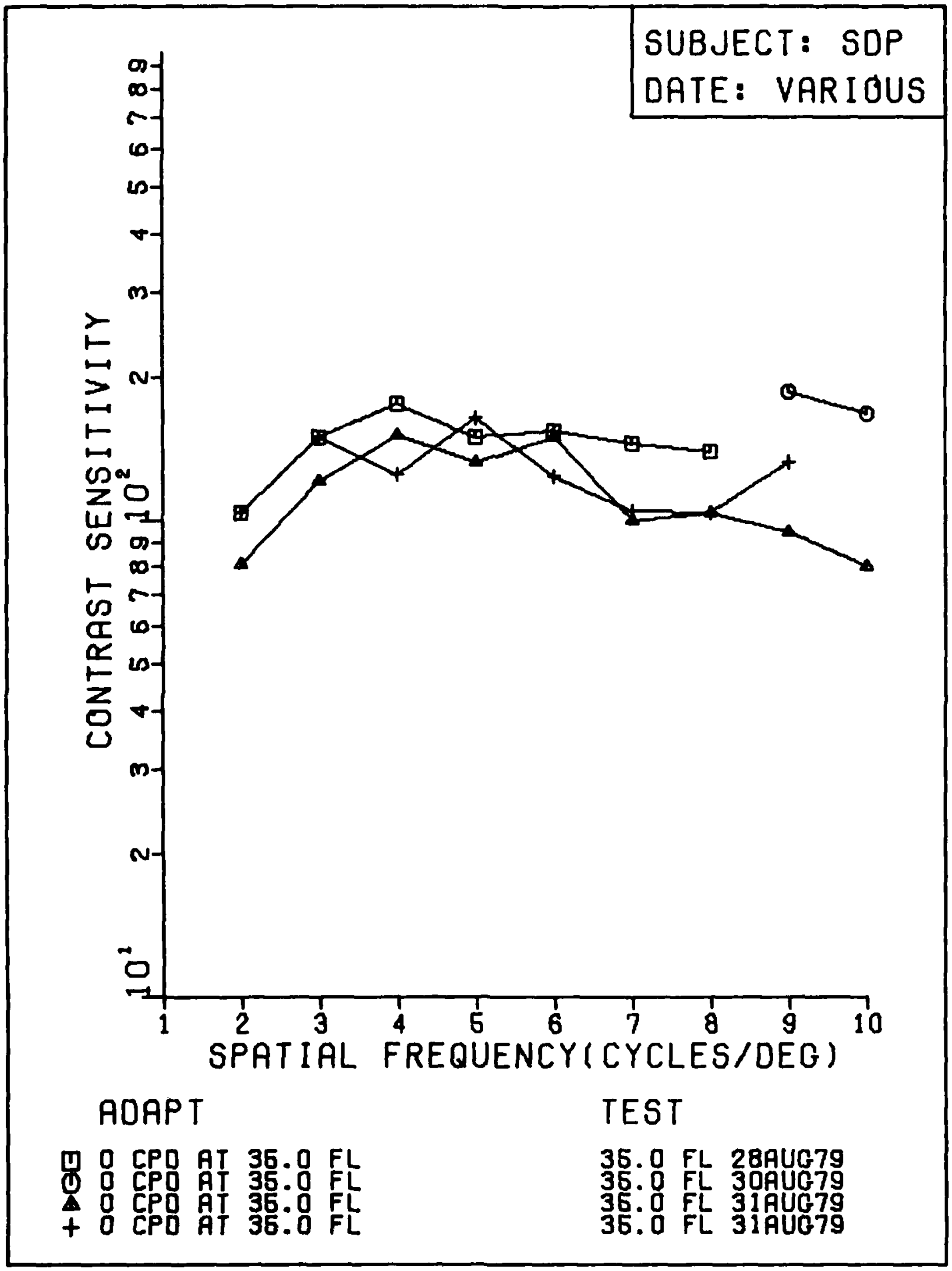


Fig. 57 SDP, Various

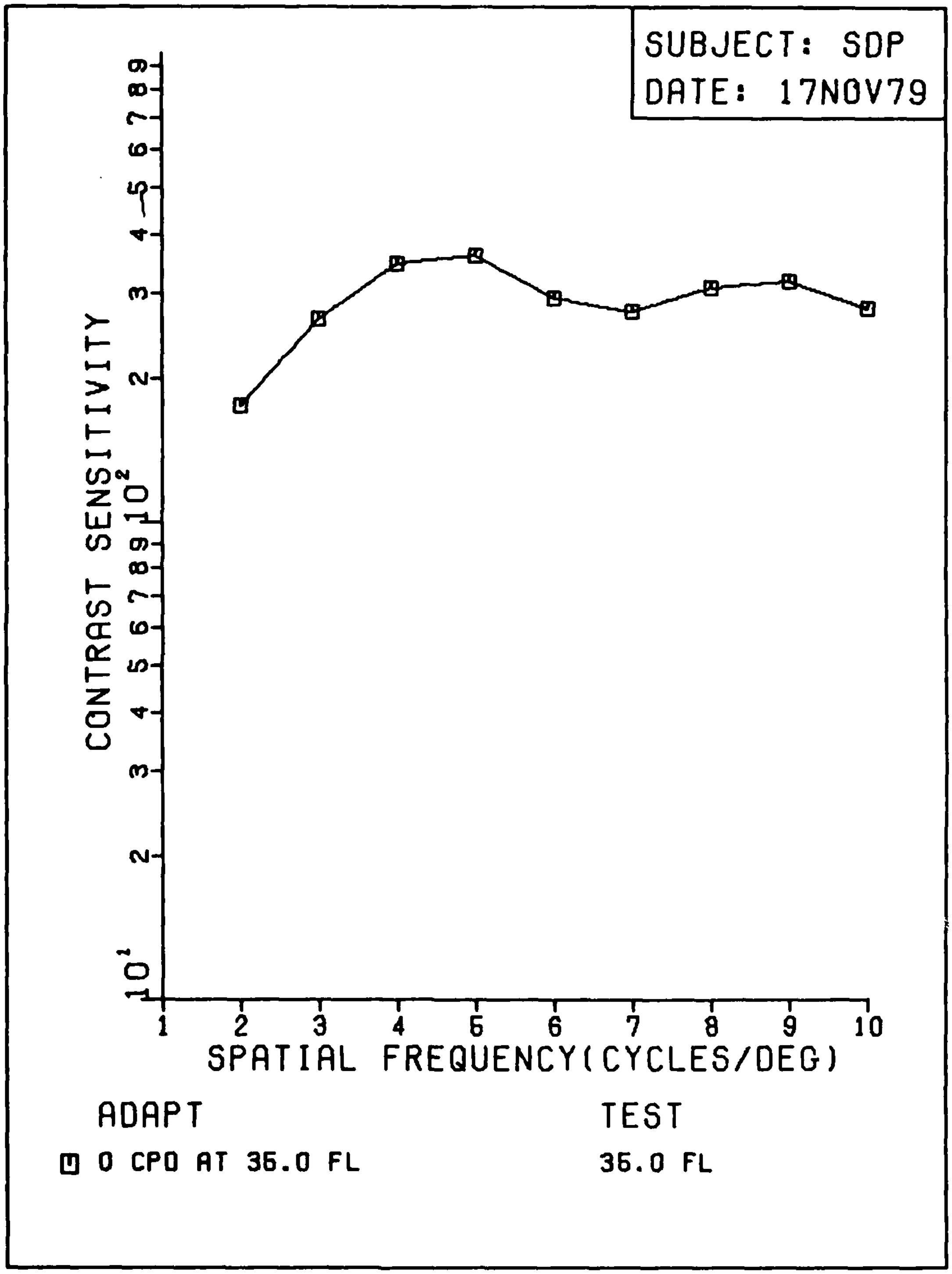


Fig. 58 SDP, 17Nov79

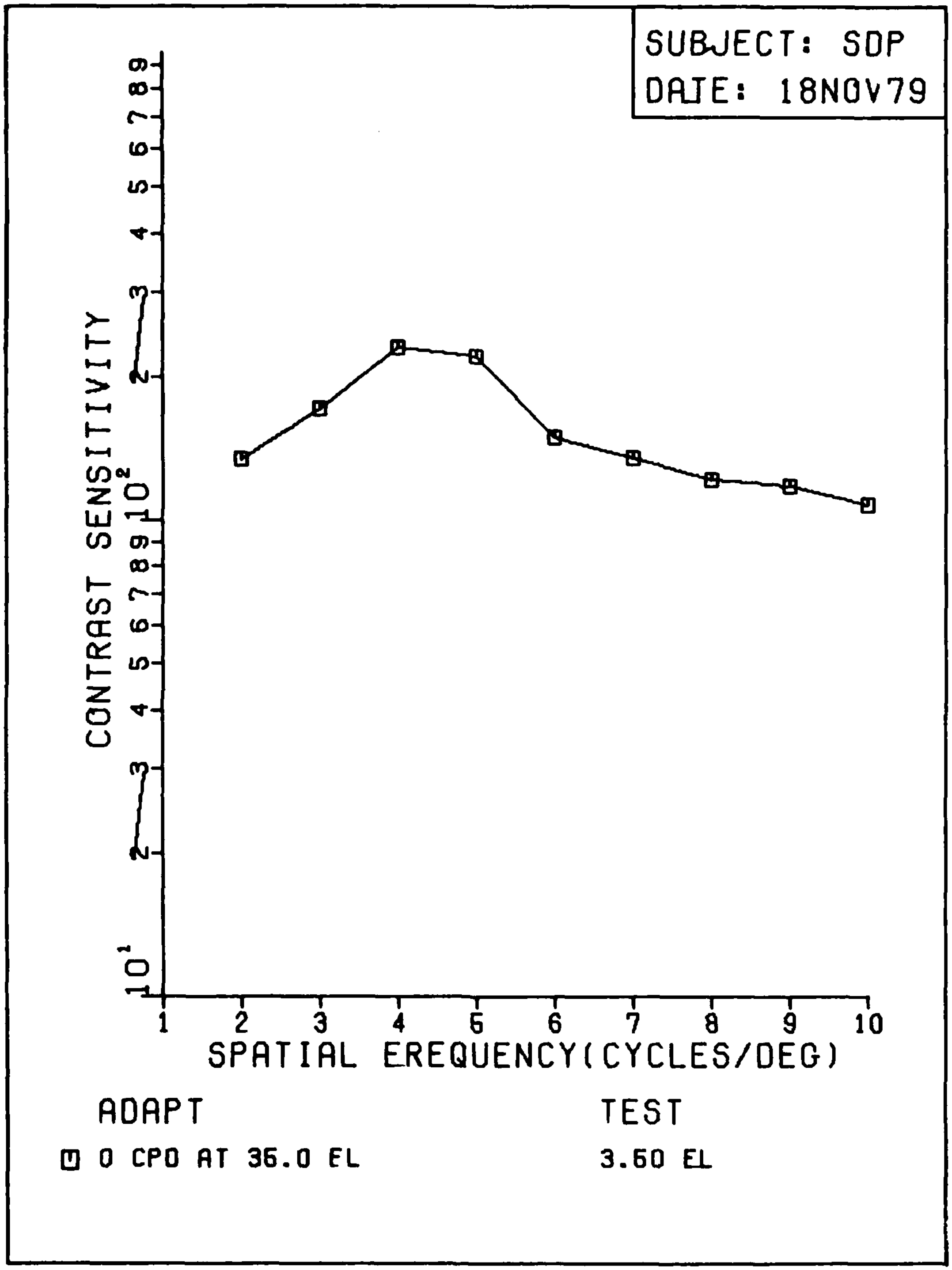


Fig. 59 SDP, 18Nov79

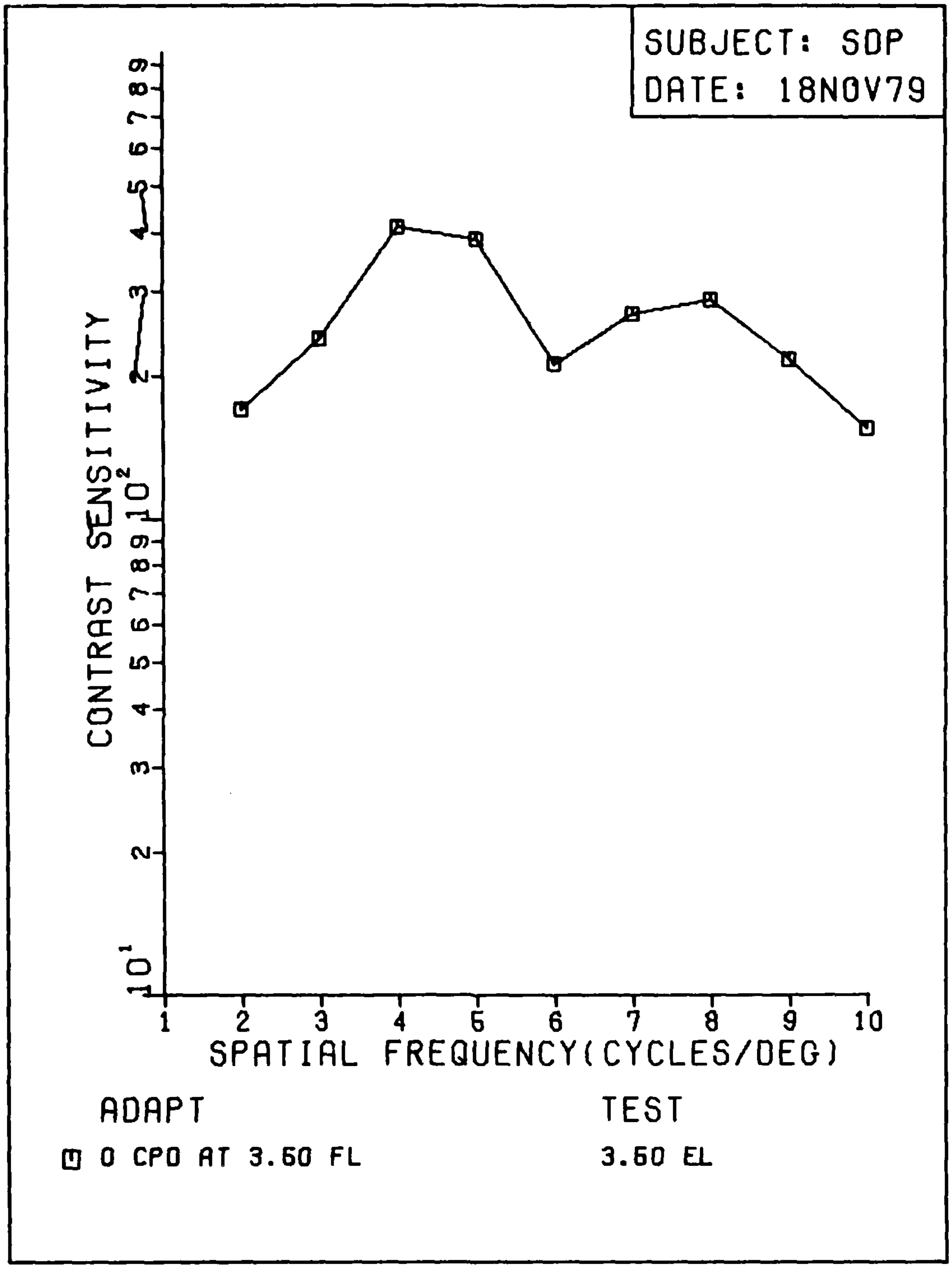


Fig. 60 SDP, 18Nov79

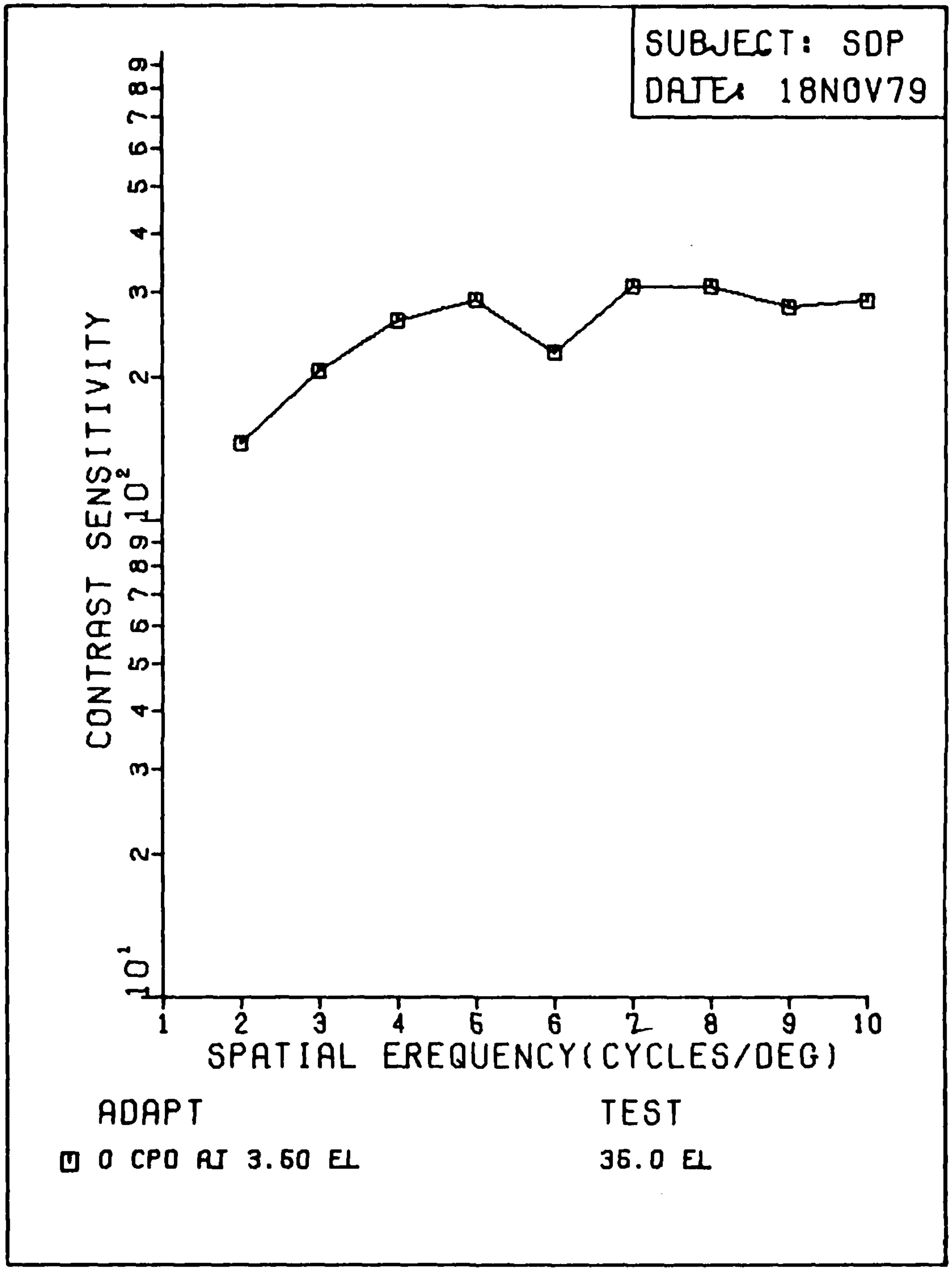


Fig. 61 SDP, 18Nov79

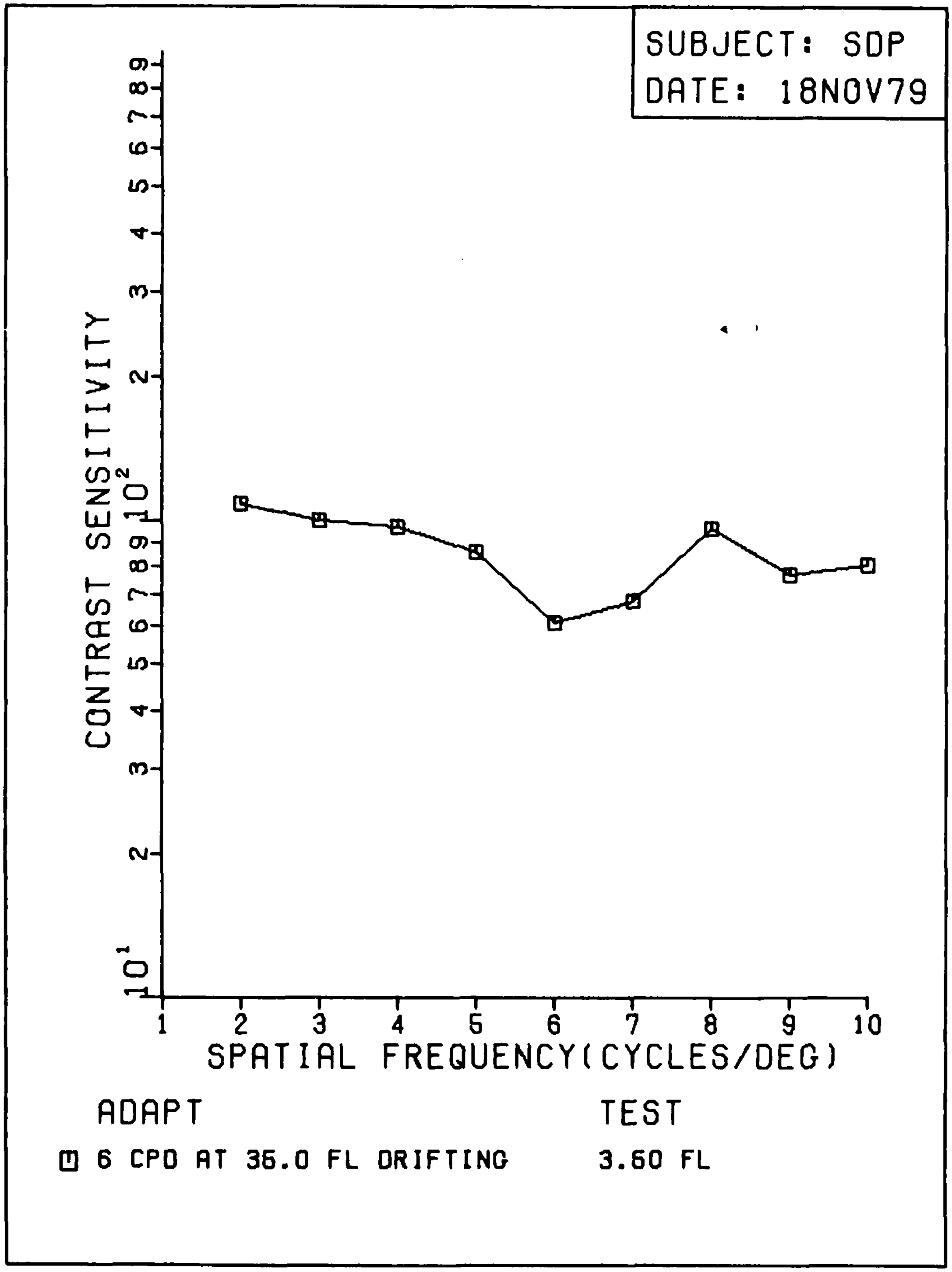


Fig. 62 SDP, 18Nov79

SUBJECT: WAC

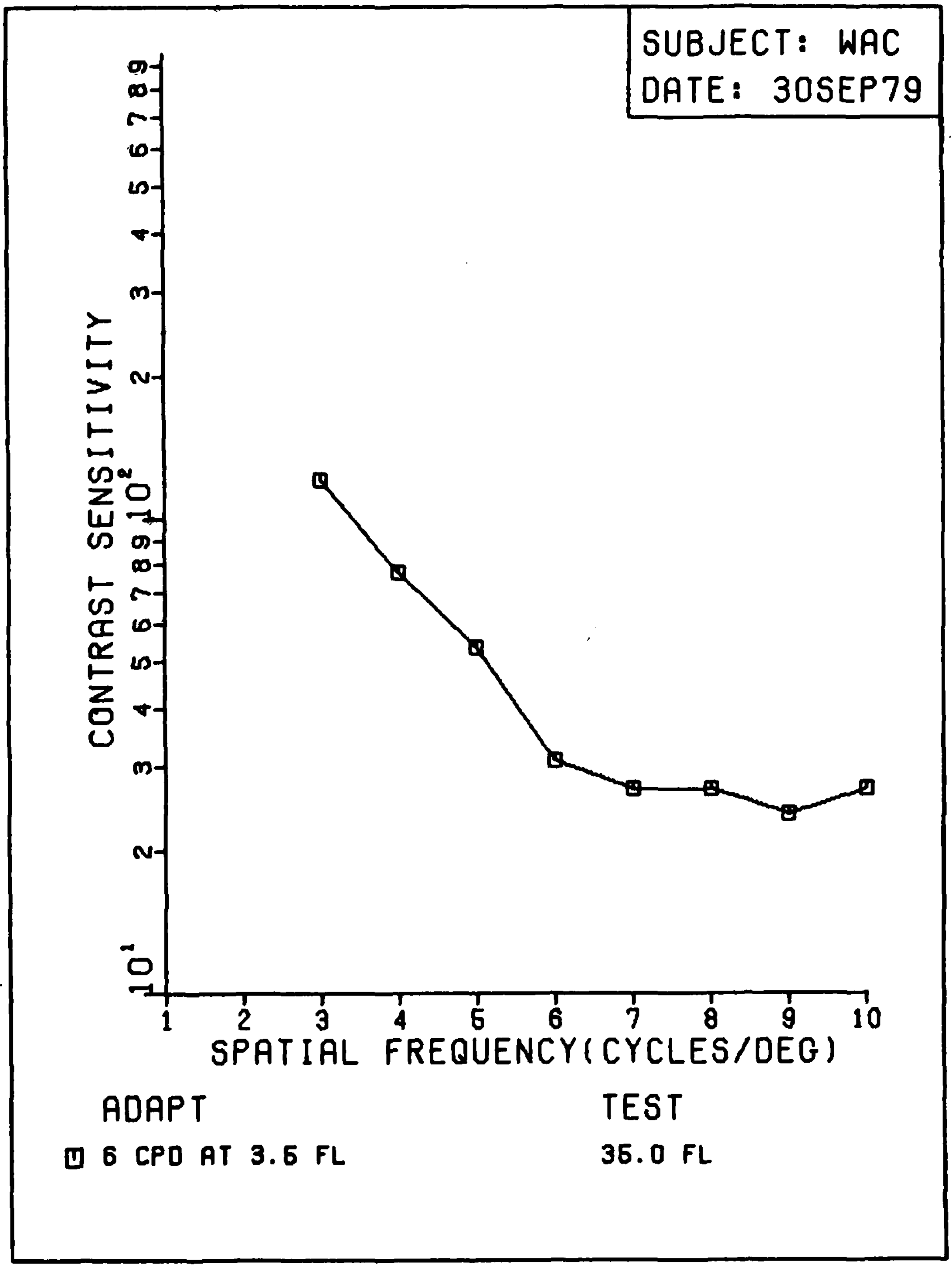


Fig. 63 WAC, 30Sep79

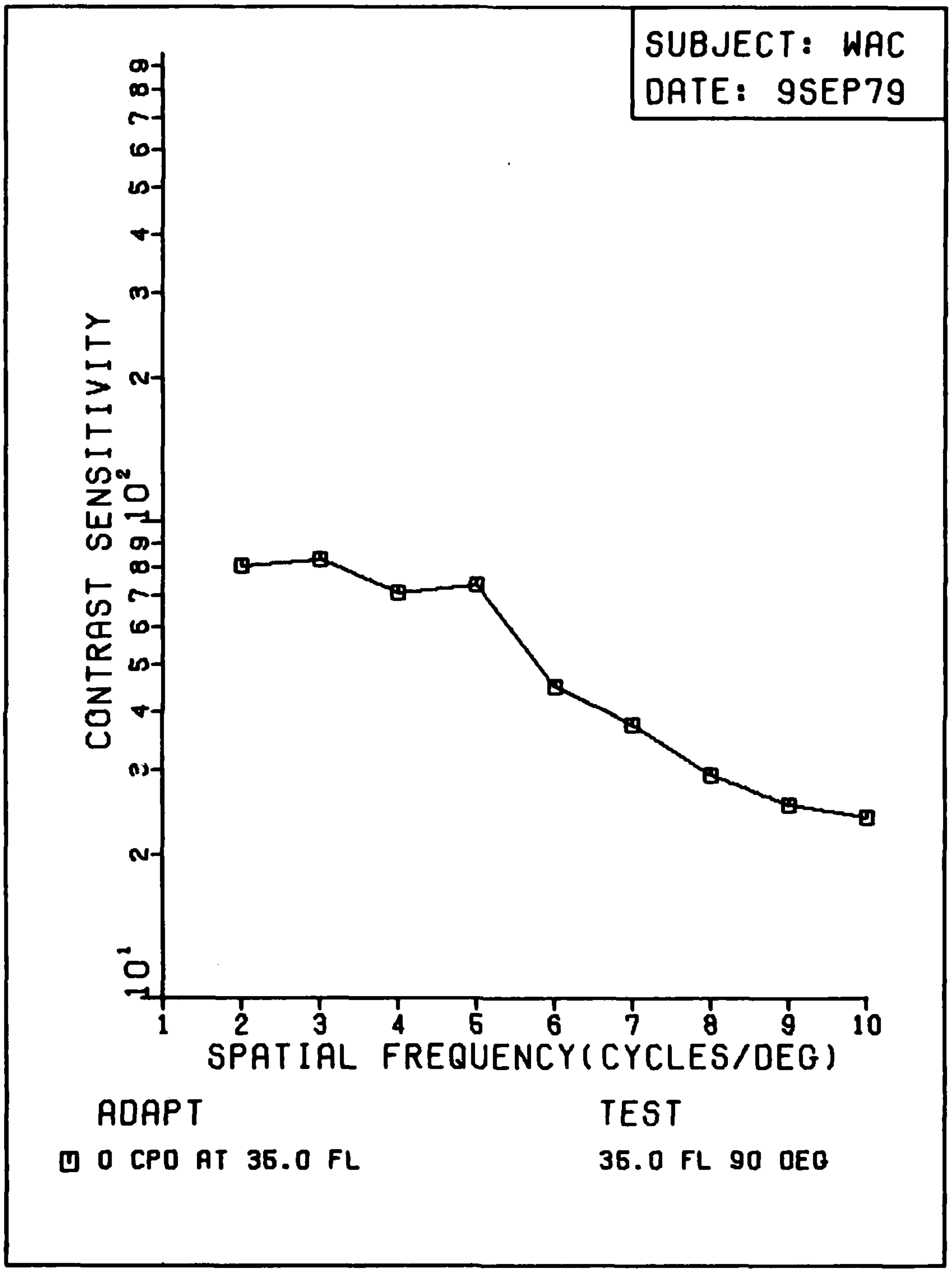


Fig. 64 WAC, 9Sep79

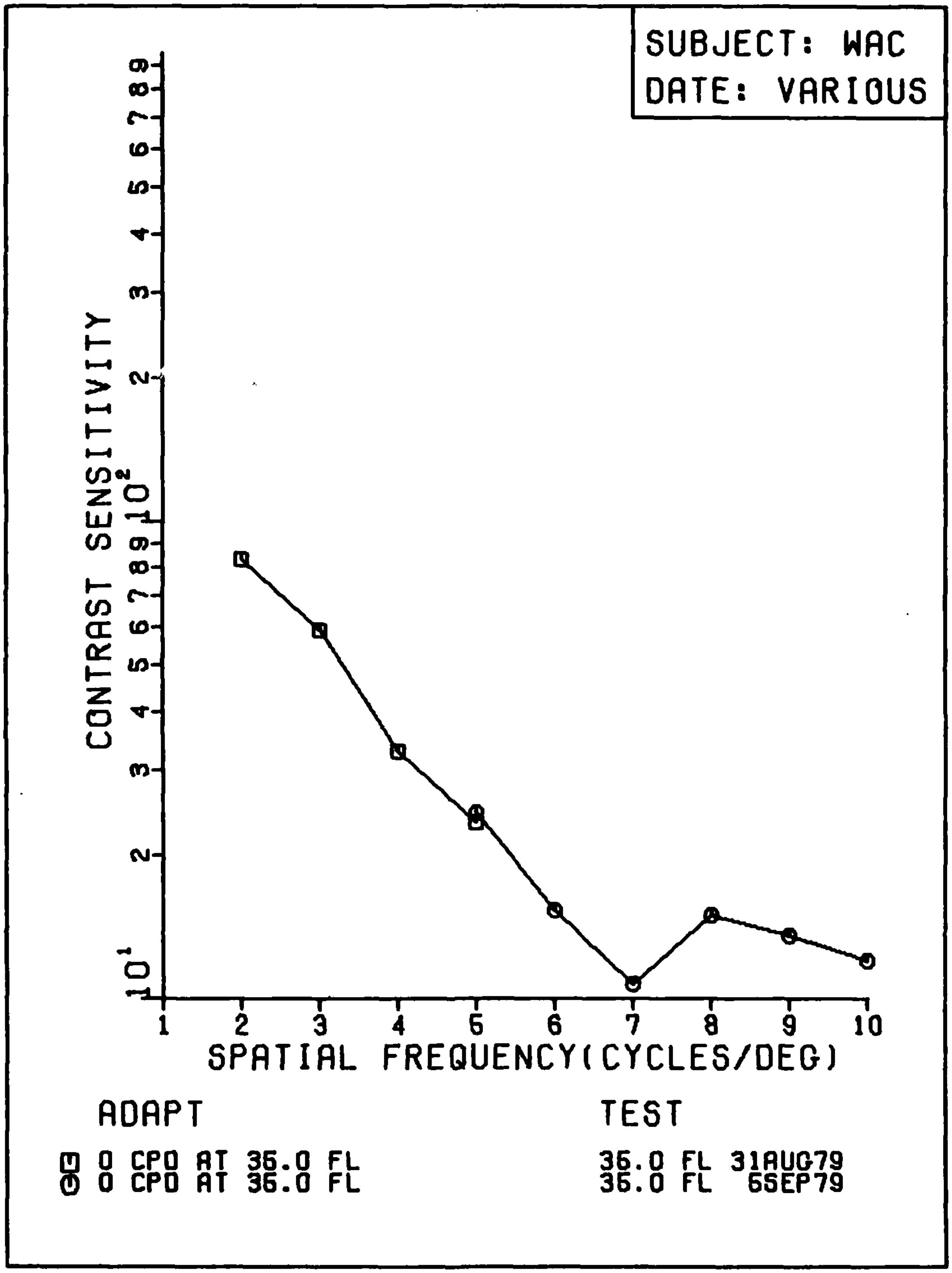


Fig. 65 WAC, Various

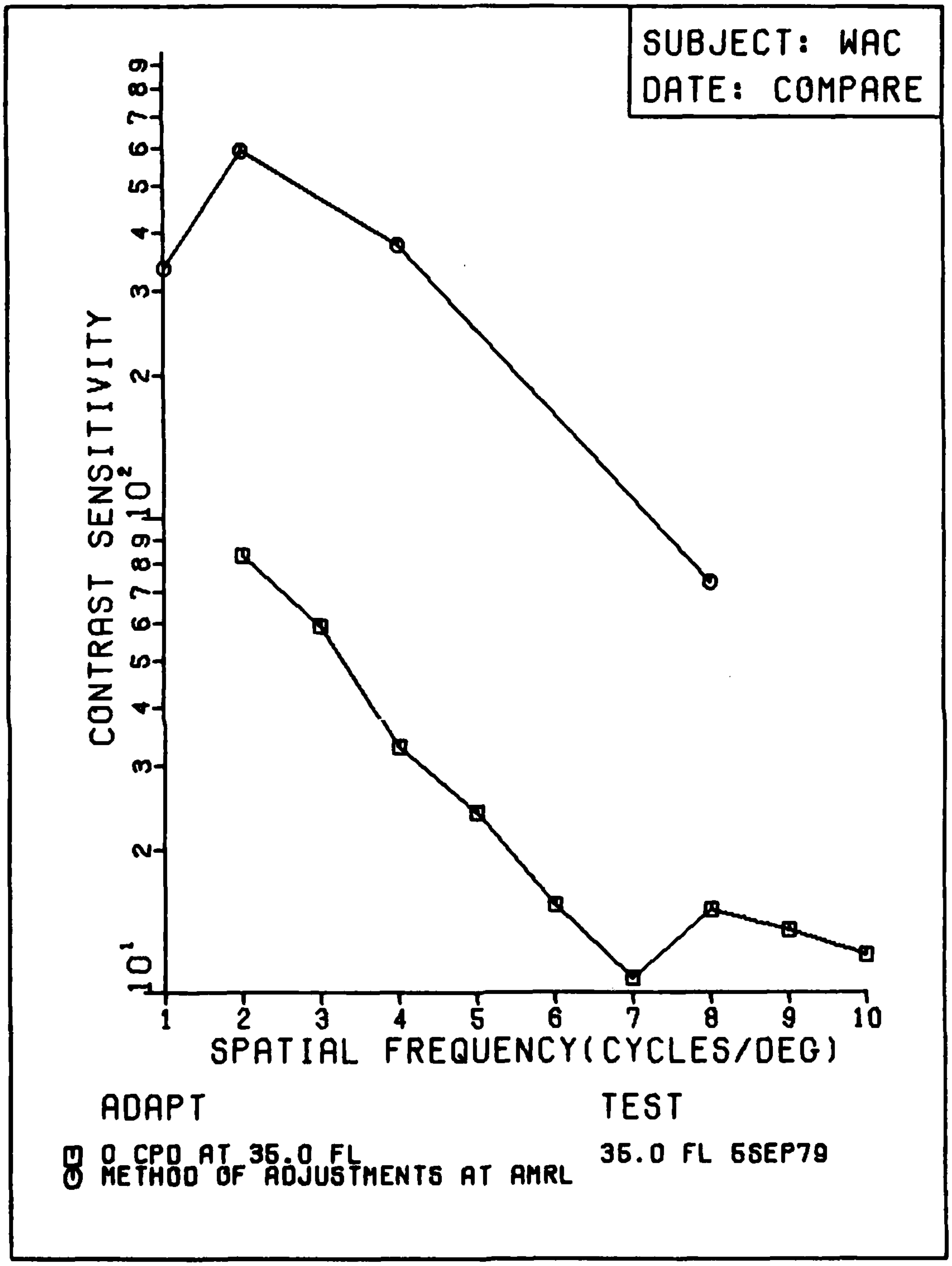


Fig. 66 WAC, Compare

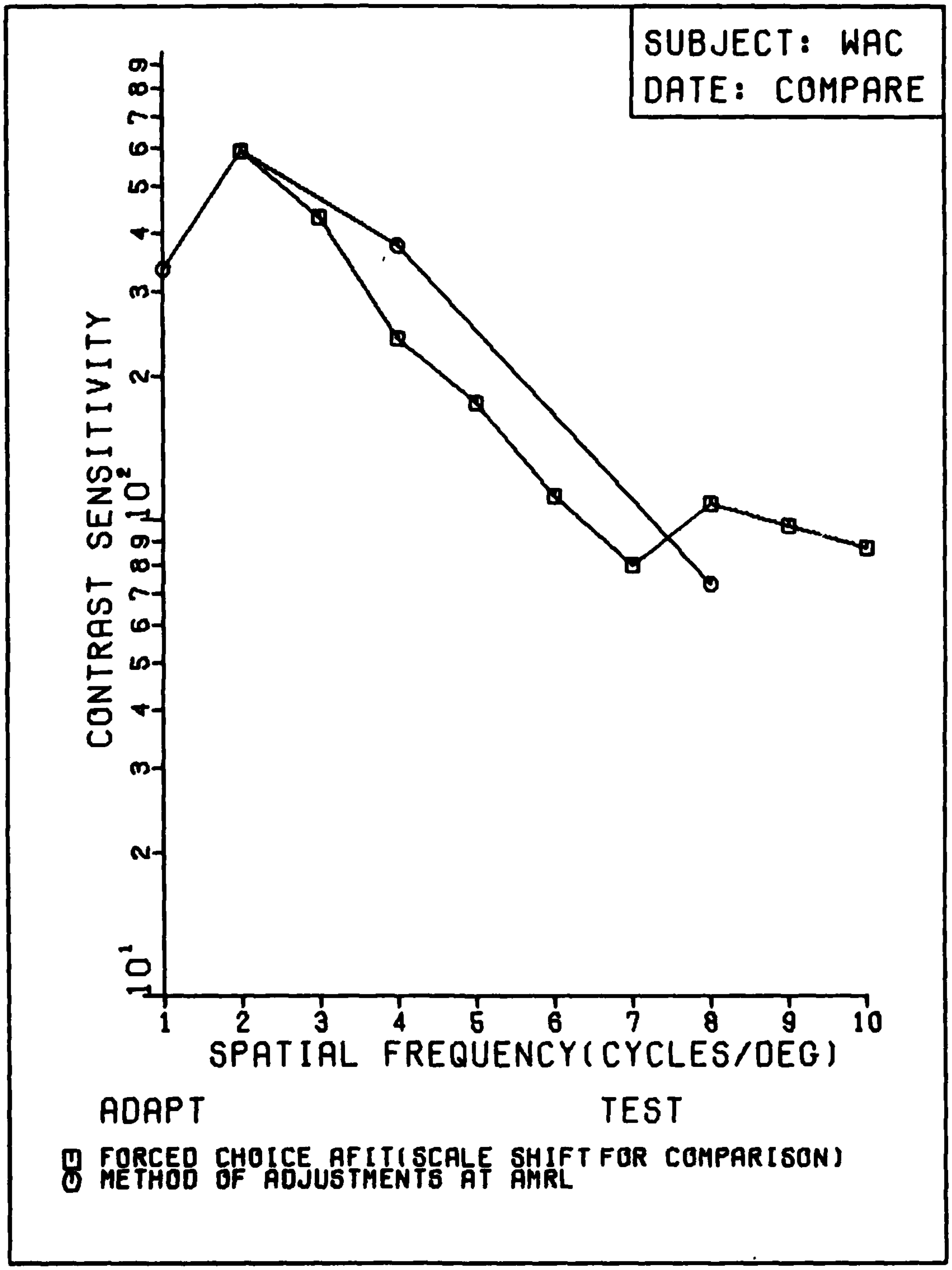


Fig. 67 WAC, Compare

SUBJECT: WPN

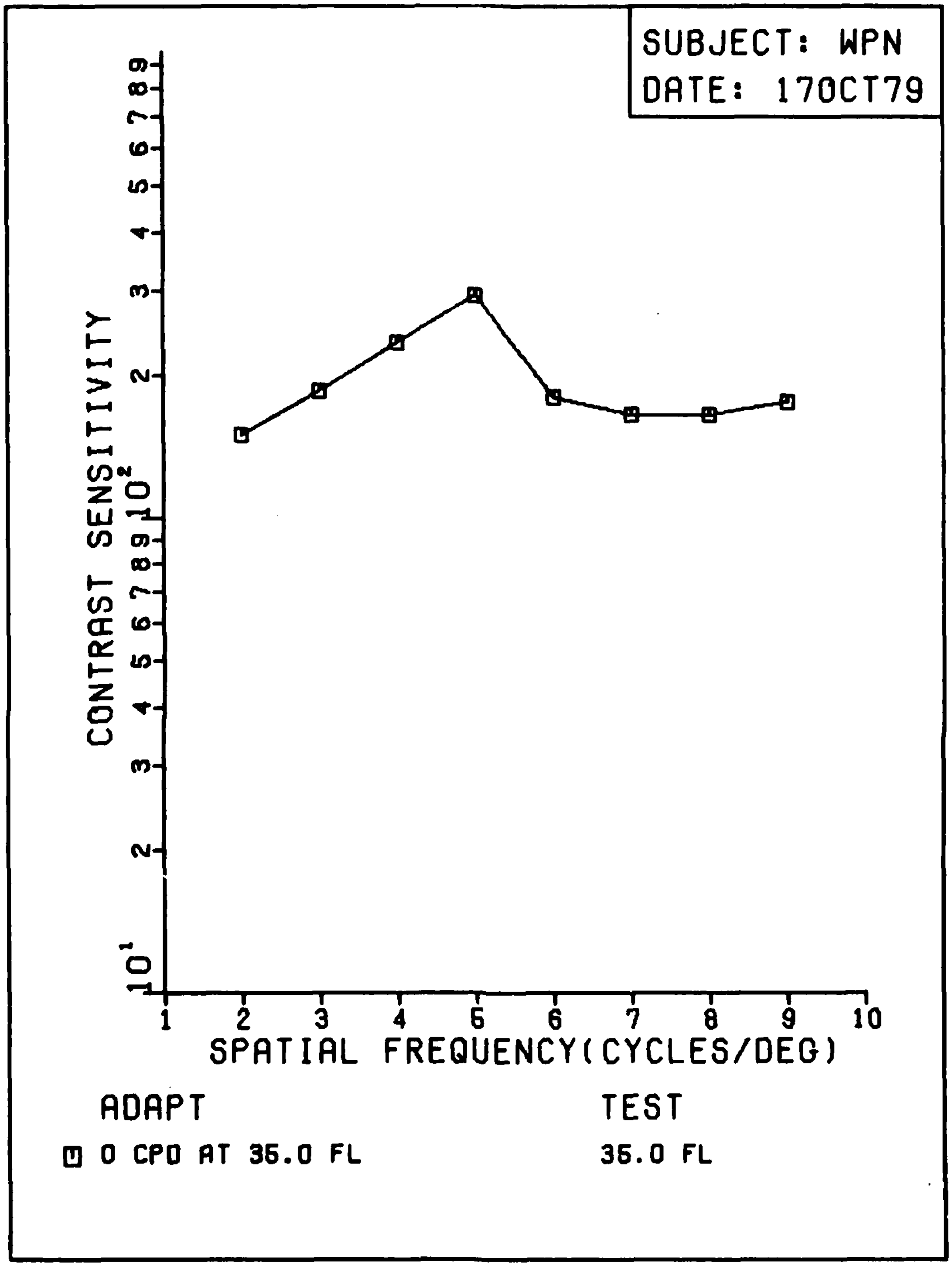


Fig. 68 WPN, 17Oct79

SUBJECT: CGS

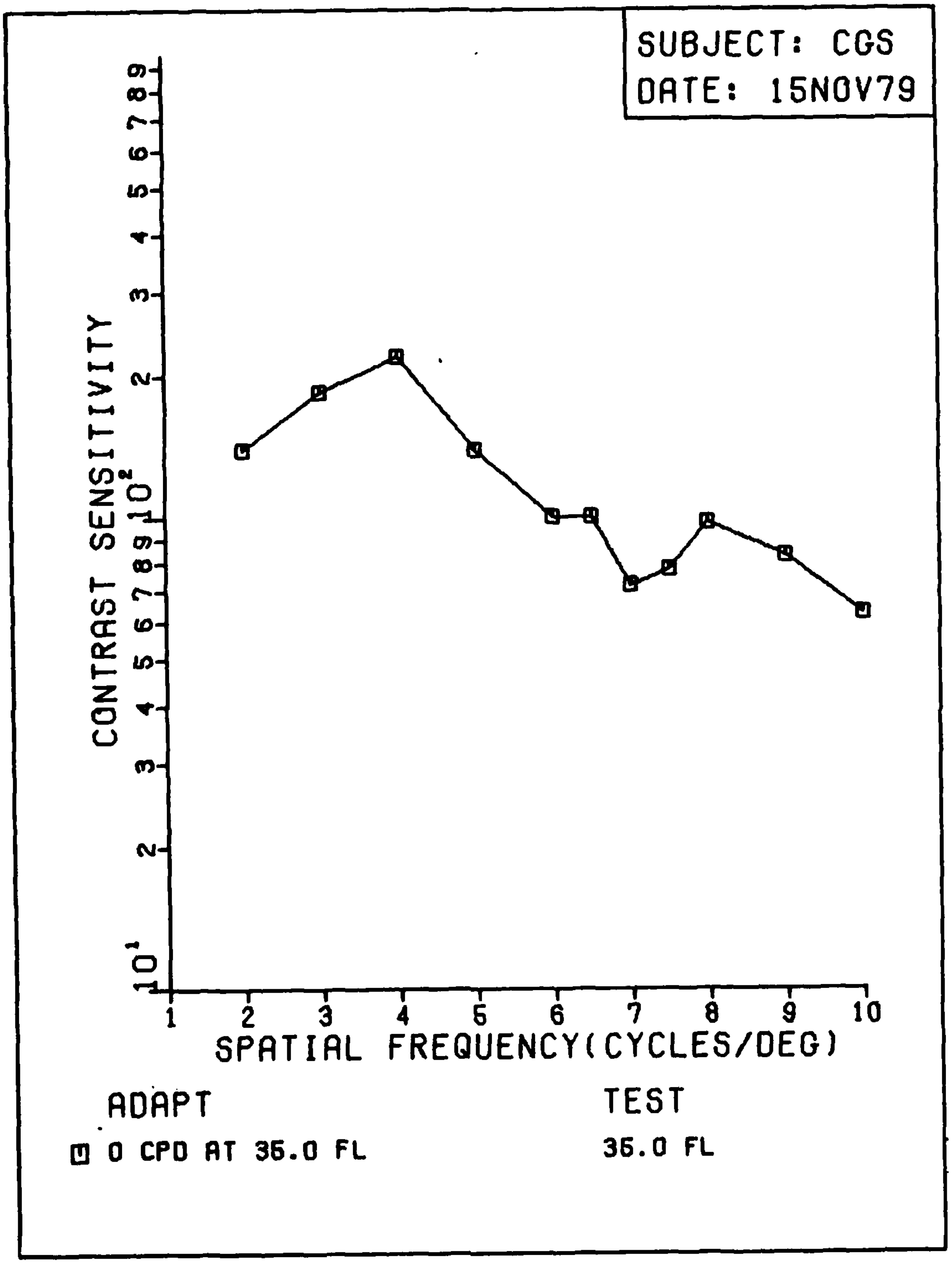


Fig. 69 CGS, 15Nov79

# VITA

William A. Clemens was born 18 January, 1953 in Lewisburg, Pennsylvania. He graduated from Milton Area Senior High School in Milton, Pennsylvania in June, 1970. He attended Grove City College, Grove City, Pennsylvania, where he graduated in May, 1974 with a Bachelor of Science Degree in Electrical Engineering. While attending Grove City College, he participated in the Reserve Officer Training Program. He was commissioned as a second Lieutenant in the United States Air Force in May, 1974. From November, 1974 thru May, 1975 he attended the Communications Electronics Engineering Course at Keesler AFB, Mississippi. In June, 1975 he was assigned to Hill AFB, Utah, as the Chief of Maintenance for the Communications Squadron where he spent the next three years. In June, 1978 he was assigned to the Air Force Institute of Technology, Wright-Patterson AFB, Ohio.

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19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Human Modulation Transfer Function
Adaptation
Sensory Adaptation Effects
Spatial Frequency Adaptation

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report documents an investigation of a hypothesis, based on a receptive field model of the visual system, proposing that the receptive field organization changes in response to a change in the average luminance of the visual stimulus.

Foveal measurements of sinusoidal spatial frequency contrast sensitivity over the range of 2 to 10 cycles per degree were made using a two period

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) forced choice stimulus. Measurements were made at one luminance level while subjects adapted to a 6 cycle per degree sinusoidal grating of the same or different average luminance. The two luminance levels used were 3.50 and 35.0 ft. lamberts.

Testing with adaptation at the same luminance produced a depression in the contrast sensitivity centered over the adapting spatial frequency. Adapting with a different average luminance level failed to produce a shift in this depression. Results obtained for tests without adaptation provide evidence, however, that a change does occur in the visual system as a result of a change in average luminance.